

Retrofitting conventional houses inexpensively to improve energy efficiency

Anthony Weaver

B.App.Sc. (Min. Eng.)

Dip.Ed.

Grad.Dip.Env.Studies

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Declaration

This work contains no material which has been accepted for the award of any other degree or graduate diploma in any University or other tertiary institution and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference has been made in the text.

A handwritten signature in blue ink, appearing to read 'Tony Weaver', with a stylized, cursive script.

Tony Weaver

December 2004

ABSTRACT

This research is founded on the notion that energy efficiency should be a standard design characteristic of all housing, and that government action to mandate performance standards for new homes fails to recognize that most people live in existing, often inefficient dwellings. Factors contributing to the nature of existing housing, advantages of energy efficient homes and reasons for the lack of up-take of energy efficiency are investigated. The multi-scalar context for improving existing housing is presented, outlining the international movement towards sustainable development, which embraces sustainable housing and the implicit equity issues of good housing being an essential need for all people, in particular the disadvantaged. The heat transfer principles, techniques and potential benefits of conducting a retrofit to improve the energy efficiency of older conventional housing are researched and a case study retrofit carried out. Four rooms of the study house were monitored for room temperature for one year before the retrofit and then for a further year, and on-site external temperatures were also recorded continuously. Despite some site constraints, including extensive shading of the house, improvements in thermal comfort conditions in the house have been observed, together with a small overall reduction in energy consumption. Most significant were the improvements in the health of family members, especially that of the children, with lower frequencies of ill-health reported and much more rapid recovery times. These findings confirm a growing body of international research linking poor quality housing with higher rates of respiratory and cardiovascular disease and increased winter mortality levels. Traditional cost-benefit assessments of energy efficient retrofits have considered financial and, more recently, environmental factors, but need to be expanded to include the substantial, but difficult to quantify, social gains associated with enhanced quality of living environment and occupant health.

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Through the slanting rain in the headlights the For Sale sign with the large SOLD sticker slapped across it was a demoralising sight. The cottage almost at the limit of the car lights looked most appealing – just what I was dreaming of for my first home – and just where I wanted to live. I returned to my rented sleep-out and only rang the real estate agent back because I had told his wife I would, when I rang earlier to find out if it had sold, and he had been out. That act of politeness in the face of defeat saved me. He wondered if I would mind a cottage like that with more land. Mind? I'd prefer it. Well, he had one coming up soon as a deceased estate. Where? Right next door. I pestered him for weeks as legal arrangements dragged on, until he assured me that I was the only one still interested. The 120 year old mudbrick cottage on a couple of acres in a quiet, scenic part of the Adelaide Hills was to be mine.

Eventually, in the middle of the first Oil Crisis, I gained custody of the property, which had been in one family from the time it was built circa 1850. The rear of the four-roomed cottage was perched at the top of a north-facing slope, although I knew nothing of the value of this. As I recall the north wall had but one window in it. This window was about 45 centimetres square, broken, and when I lent a five metre plank up to it, it provided access to the house for my new kitten. Within a year I built an extension out from the north wall – a bathroom, laundry and toilet (as it lacked these), and a second bedroom in the north-west (which I later came to refer to as 'the sunroom'). No publications on energy-efficient house design had yet reached the bookshops of Adelaide, even if I'd been looking.



CHAPTER 1: INTRODUCTION

1.1 Background

1.1.1 Global Context

The issues of sustainable development are becoming increasingly acute as the level of resource consumption continues to rise in the industrialized countries, and begins to climb in the developing nations (OECD 2001, Worldwatch Institute 2000). OECD figures show that from 1980-1997 Australian electricity consumption rose by 80%. The oil crises of 1973-4 and 1979-80 resulted in several national governments instituting programs to improve residential energy efficiency of both existing and new buildings to relieve pressures on oil stocks. Once oil prices fell, some governments felt the imperative had been removed. Nevertheless there has been a consequent reduction in household energy consumption per household, but overall residential consumption has increased due in part to the increasing number of households, and in part to a decrease in household size (Ekins, Russell and Hargreaves 2002, p.42). International scientific concern at the potential for uncontrolled increases in carbon dioxide emissions to contribute to global climate change through enhanced greenhouse effect has fuelled renewed interest in improving residential energy efficiency since 1990 (Houghton, Callander & Varney 1992, Healey 2000). The residential sector is a major contributor to resource consumption and greenhouse gas production, as well as air pollution from coal-fired power stations, as it accounts for 22 per cent of global energy consumption (Parker, Rowlands & Scott 2003, p.169). Currently there is a global movement to create more sustainable buildings. At the 2002 Johannesburg World Summit on Sustainable Development, detailed submissions were made by the International Council for Research Innovations in Buildings and Construction, as well as the Confederation of International Contractors Association, on the new agenda for building. Nationally, the Australian Building Codes Board has suggested 'environmental sustainability as a goal of the Building Code of Australia in future reviews.' However, the Federal Government sends a mixed message to both the global and Australian communities on sustainability by not ratifying the Kyoto Protocol to reduce greenhouse gas emissions to the level of eight per cent above 1990 levels, for which it negotiated a special dispensation. In its 2004 environmental policy statement the Federal

Government also indicates it is less interested in the practice of renewable energy than in the theory of geo-sequestration, a preference that privileges coal and petrochemical producers who will receive grants to research unproven theories and have no incentive to decrease emissions. Renewable energy production is a proven source of pollution-free energy, but remains an under-resourced industry.

1.1.2 Local Context

While the Federal Government fails to increase support for sustainable energy production, some of the Australian States and Territories have taken steps to mandate improved energy efficiency in new home design. The Australian Capital Territory has introduced a five star energy rating requirement for new homes and mandatory disclosure of home energy rating at point of sale for existing homes (Public Works 2004). Victoria introduced a new five-star energy rating requirement in conjunction with the Building Code of Australia for all new homes from January 2003, while Tasmania opted for a four-star requirement from the same date. These initiatives focus on new structures, which constitute a mere 2 per cent of the built environment (Harrington and Foster 1999a, p.42).

Tasmania has the oldest housing stock in the nation, 23 per cent of homes having been constructed before 1955 (ABS 2000). With the highest proportion of timber homes in the nation (32 per cent) (ABS 2003), the Tasmania building stock has a particularly low energy rating. The bulk of housing is poorly constructed and maintained for energy efficiency but will be lived in for decades to come. Legislative changes to the Building Code will take years to have impact on a significant proportion of the building stock. One reason for the significance of this thesis is that 'energy efficient new dwellings only serve to limit the rise in energy consumption and do not reduce the current energy consumption' (Oreszczyn 1992, p.176), so it is necessary to seek ways to upgrade the efficiency of existing homes now.

In addition to the environmental arguments for improving residential energy efficiency, there are some pressing social reasons. In his Barnett Oration on Sustainability and Housing (September 2002), Professor Peter Newman noted that one of the overlooked foundational principles of sustainable development embraces

equity and human rights. Given a choice, most people would prefer to spend less for essential services, but Australian Bureau of Statistics figures (2004) show that for 40% of Tasmanians, income support is their primary income. A social report by Anglicare (2002) indicates that for many financially disadvantaged Tasmanians a choice must frequently be made between paying their electricity power bill or food purchases. The disadvantaged stand to gain appreciably by being able to reduce their expenditure on energy and enjoy the benefits of an improved quality of life, if improving the energy efficiency of their home also raises their comfort levels. Beyond comfort issues, there are various health implications of living in poor housing with rooms too cold (WHO 1989), too damp (Somerville *et al.* 2000), and too mouldy (Huby 1998). There has been very little research in Australia on the impacts on the occupants' health of energy efficient retrofits to their housing. If people can be motivated to make the requisite modifications to their home for minimal expenditure, they also will have gained from the principle of self-reliance (Galtung 1979).

There is a wealth of literature on the need for energy efficient houses and on interesting ways for those who are financially able to plan and construct them, but a dearth of practical information on what people in conventional, poorly designed homes can do to improve the circumstances in which they find themselves. The latter may plan a renovation without encountering the concept of making it both energy efficient and an enhancement of the house. Renters do not even own the space they occupy. There is a need to find ways to facilitate change for renters as they can do little to alter their housing conditions.

1.2 Aims and Objectives

Sustainability has been delimited as a normative concept and set of practices by which to live (Armstrong & Stratford, 2004). According to the Western Australian Government (2004), firstly, it embraces seven foundational principles: long term economic gain; access, equity and human rights; biodiversity and ecological integrity; settlement efficiency and quality of life; community, regions, 'sense of place' and heritage; net benefit from development; and common good. Second, it requires the application of four process principles: integration; accountability, transparency and engagement; precaution; and hope, vision, symbolic and iterative

change. The purpose of this thesis is to investigate questions of equity, settlement efficiency and quality of life and the common good by examining why there are so many houses with poor energy efficiency when it is so easy to design them better, and to make existing houses work better. Why is energy efficiency in housing so rarely a priority of governments, builders, or even of residents? Why is it the case that virtually the only focus for improving energy efficiency in housing is on new homes, when there are so many existing houses and so many disadvantaged people living in them (often as tenants), with no chance to acquire a new one? Such questions require attention to all four of the process principles of sustainability noted above.

Given these broad aims, my particular objectives are to investigate various factors that have contributed to the proliferation of inefficient housing. As part of that task, I will specifically test and document the gains to be achieved in a house built in the Hobart suburb of Taroona in the 1890s and owned by the Hobart City Council, by retrofitting to improve its energy efficiency. This intrinsic case study (Stake 2000), undertaken for its own – rather than comparative – merits, is designed to elicit gains in comfort and reduced energy use. Two particular conditions of the retrofit assist in my exploration of the relationship between energy efficiency and equity and quality of life outcomes. The first is that the retrofit should be undertaken for the least possible cost. The second is that the perceptions of residents be traced after the retrofit. In this sense, the work does not represent research into the technological dimensions of sustainable housing, although it is indebted to those dimensions. It does, however, underscore the relationship between technological intervention and the mix of behavioural, political and economic factors surrounding sustainable housing.

1.3 Methodology

I bring to the investigation my experiences of living in houses which were not energy efficient and my (sometimes successful) attempts to redress their deficiencies. My efforts were informed by personal forays into Do-It-Yourself energy retrofit publications in the popular press, bolstered by investigations into passive solar design. I also taught tertiary courses in natural resource management and produced land management plans. In the Coursework immediately preceding the

commencement of this thesis, my practical past and personal commitment to sound ecological and environmental practices was invested with the rigour of sustainability and values studies, as well as the principles and aims of environmental planning.

The principle that sustainable development meets the needs of the present generation without compromising the ability of future generations to meet their needs contains within it two key concepts: that of 'needs', particularly of the essential needs of the poor; and that of the limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs (WCED 1987, p.43). Housing is an essential need, not just of the poor, but there is a fundamental level of quality of housing that is required. Recognition of the need for minimum standards in housing is consistent with recognition of 'quality of life' criteria, whereby people have a right not just to life, but to a fulfilling life and all that entails (Davidson 1999, p.31). Provision of appropriate housing is not limited by the state of technology, but by some aspects of social organization, and those social factors were also a focus of my attention in this study. There are 'top-down' bureaucratic factors and 'bottom-up' personal and community factors to investigate when seeking to understand the lack of promotion of sound energy efficient housing. The local government-based actions promoted in Agenda 21 from the 1992 Rio Earth Summit on Sustainable Development provide useful strategies for change. The notion of self-reliance (Galtung 1979) is also implicit in this thesis, for if ways to improve housing can, at least in part, be undertaken by the occupants then empowerment and self-fulfilment follow and enhance quality of life.

Finally, there were ethical issues of intrusion into the personal space of five people in order to monitor their living environment before and after ringing changes on it. The members of the family have been most helpful, the parents providing qualitative information which has informed the study in significant ways, and they have all shown interest in the study of their residence.

1.4 Scope and Characteristics of the Thesis

The thesis focuses on ways to improve existing housing and seeks to prioritize methods for energy efficient upgrades of homes which are affordable for average- to low-income and disadvantaged groups. While the 'top-down' and 'bottom-up' social

factors affecting up-take of energy efficient housing were both researched, the way to effect change in the efficiency of existing housing is by actions at personal and community level, so local government and community-organized ways to enhance that prospect were investigated in greater detail. The research is intended to find methods applicable to people improving housing in Tasmania, but results would be expected to be valid for occupants of most housing in cool temperate and temperate climates.

There are some characteristics of the thesis which influence the breadth of the study. I commenced a little late in the academic year of 2002 (April) as I received delayed notification of the award of the Tim Monks Environmental Scholarship which supported my studies. Originally my work was to be completed in 12 months and, in retrospect, I commenced monitoring the house in my case study before I had done sufficient research to consider measuring a greater range of environmental variables such as humidity and the temperature of internal surfaces of external walls. The case study may have benefited from the commencement of on-site external temperature measurements in June 2002 with the internal temperature monitoring, rather than in November 2002 so that there was a full comparison with winter 2003.

The investigation of the effects of a retrofit on only one house means that results may be site-specific, but I hope that it inspires further studies on a broad range of housing. In my case study I made no attempt to monitor or influence the energy efficiency or consumption behaviour of the occupants, although my research did cover influences on behaviour. When assessing the net energy consumption of the household before and after the retrofit, I did not take into account the embodied energy in the retrofit materials as considered in detailed life-cycle analyses of homes (Fay 1999).

My case study has not sought detailed quantitative data but has benefited from a combination of both on-site data recording and the important qualitative information provided by the occupants.

1.5 Thesis Style and Structure

The thesis is richly informed by both qualitative and quantitative information, and consequently has varied 'voice' in its presentation. Each chapter commences with a

vignette from a section of the author's personal narrative. The narrative spans the years during which the author was learning about energy efficiency issues through experiences with properties he lived in, a time which extends to the commencement of this thesis.

In chapter two I tease out the history of the development of the inefficient housing which pervades our country now, before putting the case for efficient homes. The reasons why we have not followed a process of establishing broad-scale energy efficient housing are then explored.

The basic principles of heat transfer and how thermal comfort is assessed are considered in chapter three, followed by considerations of the amount of energy required to attain thermal comfort. Building on these heat transfer principles I use chapter four to present the range of retrofit options available for making improvements to energy efficiency of homes, emphasising the importance of sequence and the level of complexity and expense associated with each action.

In chapter five I step back from homes to present a context for undertaking retrofit actions, a context set in the global politics of events leading to adoption of a commitment to principles of sustainable development by many nations, and the continuing diffusion of actions to achieve sustainability down to local government level. Some of the programs enacted by local governments are detailed.

Chapter six contains the story of the retrofit of the Hobart City Council house at Taroona, Tasmania, this story emerging in both qualitative and quantitative form. Additional investigations of housing studies I carried out in the Hobart area are summarized along with some of the interest generated by the case study.

In chapter seven I undertake a synthesis of the ideas and information assembled in the course of the journey of this thesis in order to define some ways to capitalise on the experience gained. Finally I summarize the findings and make suggestions for further research in chapter eight.

One thing I did add to the extension was a pair of the newly available flat-plate solar hot water collectors and I had the plumber construct an adjustable rack so I could tilt them higher in winter. (As a child growing up in a South-East country town I had noticed how weather affected my daily movements, and early in secondary school in geography lessons my interest in climate led me to an appreciation of annual changes in sun angles.) The external hot water system I had mounted on a raised frame above the panels on the new roof. Earlier that year, 1974, Premier Don Dunstan had introduced an incentive scheme for the owners of solar-heated hot water systems: any electric boosting needed would be available at a reduced tariff. My boosting element was on a manual switch and I only used it when necessary. That summer my total power bill was \$7. I must confess to having a trained frugality. As a boy, I recall my mother saying whenever I left a light on, 'Your father only works for ETSA [Electricity Trust of South Australia], he doesn't own it!'

The fork in the road which brought me to this cottage was reached when, in 1972 I was influenced by working with an inspirational group of young colleagues who actively read and discussed emerging environmental and ecological ideas. The Stockholm Conference on the Environment was of some significance to us, and 'The Ecologist' was passed around from time to time. In 1973 one of my friends had suggested that I might be interested in the upcoming Nimbin Aquarius Festival. After making the long solo drive I was greatly rewarded by the concepts of independent, creative living being espoused in the daily brain-storming sessions. More than that, while the idea of taking responsibility for the quality of the food one ate reinforced what I had seen my parents doing in the garden, the notion of extending that responsibility to one's home energy supply represented a new awareness level for me. Now I needed a home. Within days of returning to Adelaide I had commenced the house-hunt which led, within just a few months, to the cottage at Uraidla.

CHAPTER 2: THE NEED FOR IMPROVED RESIDENTIAL ENERGY EFFICIENCY

2.1 Introduction

It is not hyperbole to suggest that the better design of new buildings would result in a 50-75% reduction in their energy consumption relative to 2000 levels, and that appropriate intervention in the existing stock would readily yield a 30% reduction. Added together, this would significantly reduce a nation's energy bill, handsomely contribute to environmental impact and climate change mitigation, and help to alleviate the stressful indoor conditions experienced by many citizens. Indeed, energy efficiency may be likened to an untapped, clean energy resource of vast potential (Clarke 2001, p.1).

There has been a great deal of research into residential energy efficiency and the possible benefits from improving it. This chapter begins with a brief exploration of the evolution of modern housing and the levels of energy efficiency to be found in much of the housing stock. Having thus seen the path taken in the development of the inefficient houses commonly constructed in the last century, it is useful to consider the full range of advantages of energy efficient homes. As the list is extensive, and the knowledge and means necessary to develop them has been available for so long, the question arises as to why energy efficient homes are not the norm. To explore these issues, I examine the role in the up-take of energy efficiency measures of various actors, from federal governments down to individual residents in an attempt to determine why apparent commonsense has not prevailed.

2.2 The Rise of the Energy Inefficient House

European Australians inherited their housing designs from their countries of origin, as typified by this contemporary description of Melbourne in the 1880s:

As members of a society still mainly immigrant in composition and expatriate in outlook, Melburnians naturally looked for domestic inspiration to their national Home across the seas. Suburban imagery was derived at second hand from older English patterns (Davison 1978, p.137).

In their countries of origin the designs were not particularly energy efficient, but translocated to an Australian setting they often were even less suitable. As Davison (1978) goes on to describe, while middle-class villas might have spacious rooms and servants' quarters, the roof had no eaves, verandahs were just an ornament on the front, and house orientation would usually have been dictated by street orientation. In addition, the artisan's cottage affordable by the working-class comprised fewer and smaller rooms, an inadequate lean-to kitchen and no verandah at all. On the broader scale, however, there was one difference from the cities back 'Home'. The desire to escape the high density living conditions in which they had previously lived, combined with availability of cheap land, meant that people began to develop suburbs beyond the manufacturing area in the city centre. As a result, spreading out around the city for some distance were rows of detached cottages that were typical of 'post-industrial immigrant societies like the United States, Canada and Australia' (Davison 1978, p.144). At that time, home ownership figures for Melbourne were particularly high by world standards. Davison observes (p.180) that from 1881-4 over 45 percent of Melburnians owned or were buying their own homes, while only three cities in America had home ownership rates above 40 per cent. Sydney's rate in 1891 was 30 percent.

In Hobart, Solomon (1976, p.156) estimates that in 1847 the rate of home ownership was 22 per cent. After the construction of an initially haphazard collection of timber homes, Governor Macquarie prepared a town plan specifying stone or brick construction only (Scott 1959, p.149), and, by 1851 when stone ceased to be used, brick housing was twice as common as timber. The restriction of building sites to the land between the foothills of Mount Wellington and the Derwent River estuary meant that Hobart exhibited sectoral growth predominantly to the north (but with some to the south) of the city centre (Solomon 1976, p.348), rather than concentric expansion seen in Australia's other capital cities. Construction in weatherboard became more popular at the start of the twentieth century and timber housing has dominated Hobart since 1921, with the 1954 census revealing 56 per cent timber homes (Scott 1959, p.150).

Similar economic influences in the USA and Australia in the middle of the twentieth century, meant that what had begun in the way of extensive areas of housing in Melbourne in the 1880s was to be repeated on an even larger scale. In the Depression

years of the 1930s there was an extended period of reduced levels of construction, which led to a great need for new homes in the USA in the late 1940s after World War II (Rome 2001, p.30). Australia was subject to similar economic circumstances and responded to them in similar ways. Estimates of the national housing shortage rose from 120,000 before World War II as a result of the Depression, to 300,000 in January 1945, although this latter estimate could made no allowance for the immigration program which saw 300,000 migrants arrive in 1949-50 (Wright 2001, p.1). In 1944 the Commonwealth Housing Commission released a report in which it planned to retrieve housing development from private, profit-making developers proposing instead a system of national, state, regional and town planning with the control of land through zoning and the control of subdivisions (p.3). The states blocked this plan for national coordination of planning, which surprisingly had been proposed before it was possible to obtain a planning qualification in Australia, the first course commencing in Adelaide in 1949 (p.6). Housing development then proceeded under state control.

Rome (2001, p.35) notes that the post-war rate of home ownership climbed rapidly in the USA to 60 per cent by 1956, resulting in an associated rise in the amount of broad-scale tract housing development, so that large-scale builders accounted for 64 per cent of housing construction by 1959. The development of tract housing in Australia was a little delayed, but by 1971 Melbourne's home ownership rate had climbed to 68 percent (Davison 1978, p.180). 'Most houses are designed by builders', observed Boyd (1967, p.29), and in addition there was a proliferation of speculation-built, 'usually un-architected, three-storey blocks of flats, with their yellow-brick walls and eavesless roofs', providing accommodation for many other people (p.24). In Hobart in the mid 1950s housing extended up the slopes to obtain river views (Scott 1959, p.152, Solomon 1976, p.348), or occupied one of several residential sectors or two broad residential tracts in the west and north-east (Solomon 1976, p.348). Orientation of homes was not to the north for energy efficiency in the cool climate. Thus the bulk of housing in the USA and Australia was designed by builders for inexpensive and easy construction, with no consideration of energy efficient design.

Furthermore, in the USA from the early 1930s appliance manufacturers had promoted their wares with increasing intensity, so that by the end of World War II

the most common image of 'the American way of life' was a single-family home replete with consumer goods. The campaign was highly successful for, in the five years after the war, while consumer spending in America rose 60 per cent, the amount on furnishings and appliances increased by 240 per cent (Rome 2001, p.42).

Yet there had been another approach to housing that gained many followers. During World War II it was possible to read an article in a popular mainstream American publication titled 'Can an old house be remodelled for solar heating?' (*House Beautiful* 85, Sept. 1943, pp. 59-66). In fact thousands of people in America bought new solar-designed houses, many of which were developments of architectural designs dating back to the Crystal House at the 1933 Chicago World's Fair (Colton 1978, p.12). This movement gained steady support in the USA, especially with the financial constraints of the 1930s and 1940s. However, by the mid 1950s aggressive promotion of nuclear energy, coupled with the discovery of major oilfields in the Middle East (Harries 1996, p.65) resulted in the price of energy reaching all-time lows in the USA, and the economic argument for conservation losing force. In the 1960s American household energy consumption rose by 30 per cent and the ubiquity of the high-energy house, heated and cooled by fossil fuels, seemed well established (Rome 2001, p.46). Such rapid rises in residential energy consumption were not universal, with France (highly reliant on imported oil) setting maximum levels of energy use for household appliances in 1965 (OECD 1976, p.23).

In Australia, there was no widespread solar home movement, despite the vision of Walter Bunning, a leader in the Modern Architectural Research Society in Sydney and a passionate advocate for post-war planning in Australia (Wright 2001, p.5). One of Bunning's favourite house designs was a 'Suntrap House' correctly oriented and admitting sun for heating (Aitken 2004, p.153), as described in Figure 2.1.

A situation similar to that in America developed in the suburbs of the cities and even in rural towns, as large housing developers established extensive new areas containing just a handful of different house blueprints. When delivering his Boyer Lectures in 1967, the renowned architect Robin Boyd observed that:

Almost everything we make here – cars, household appliances, many of the houses themselves – are copies of designs from overseas; usually from the USA, but sometimes from England, Germany or Scandinavia. Sometimes these designs are plagiarized...but more often nowadays we make the copies legally under licence (Boyd 1967, p.46).

Combined with low energy prices, the rapidly expanding electricity grid in each Australian state meant that there was little imperative to consider energy conservation in either building design or orientation, or in selection of appliances. However the oil embargo by the OPEC nations, which resulted in the 'Energy Crisis' of 1973-4, gave some impetus to consideration of energy conservation techniques, and resulted in popular publications aimed at householders suddenly concerned about rapidly escalating energy bills (Ewers 1977, Antolini 1978, Robertson 1978, Vandervort 1978). Access to ideas in such publications enabled some home-owners to upgrade the efficiency of their homes, and, combined with the interest of a few architects and consultants, such action resulted in the uptake of passive solar design techniques in some new homes. A renewed restriction in petroleum production by the OPEC nations during 1979-80 increased the focus among government and research

Homes in the Sun • 1945

Town planning received a major boost with post-war reconstruction. Walter Bunning was an influential voice with his book *Homes in the Sun* (Sydney, 1945). He lamented that the early promise of good living conditions for Australians had not been fulfilled. Bunning sought improved housing and landscape design through an alliance with town planning. He linked family needs with 'shelter answers': thus an 'elevator apartment' might answer for an individual or couple while a single dwelling would suit an invalid or a couple with children. Bunning's favoured individual dwelling was the 'Suntrap House', which incorporated appropriate solar orientation and penetration, links between indoor and outdoor spaces, and adequate ventilation.

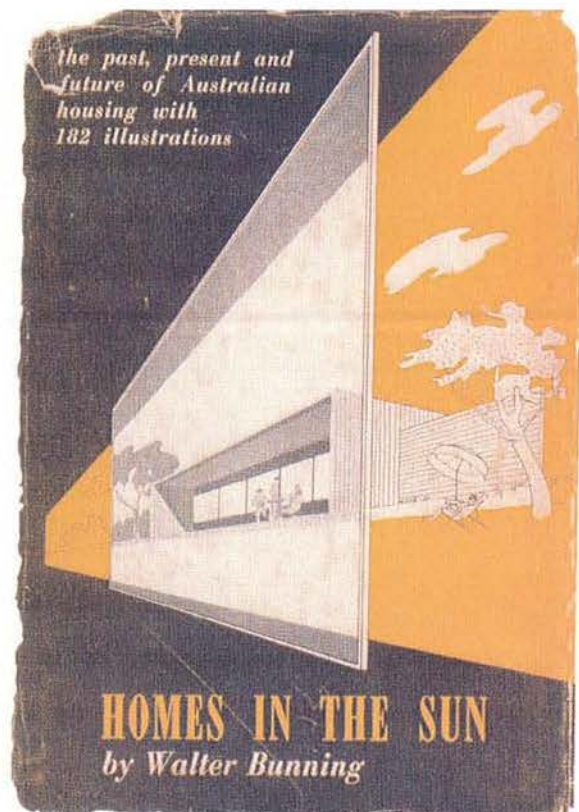
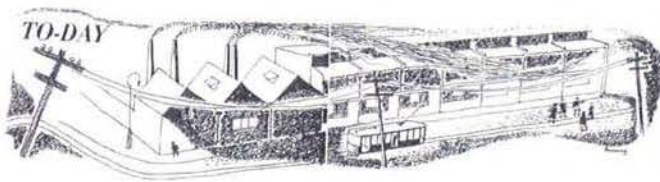


Figure 2.1: Early Australian solar design

Source: Aitken 2004, p.153

institutions on home energy efficiency in Australia and passive solar construction, the design and performance of some of which was published in comparative case studies (Greenland and Szokolay 1985, Parnell and Cole 1983). The Federal Government sponsored a major initiative promoting energy efficient house design in 1980 when it commissioned the construction of 116 specially designed homes to be used for government housing in Canberra (Greenland and Szokolay 1985, p.87). State governments in Tasmania and South Australia also supported projects aimed at improving the energy performance of public housing (Parnell and Cole 1983). However, by the mid-1980s falling oil prices largely removed the improvement of residential conservation practices from political agendas.

In the 1990s, international scientific concerns about the contribution of greenhouse gases from fossil fuel consumption to possible global warming led to a renewal of the movement to conserve energy and the impetus to seek alternative forms of energy production as part of a broader target of increased environmental sustainability. President George Bush Senior expressed his administration's disinterest in such considerations when he announced, on the eve of the Rio de Janeiro Earth Summit on Sustainability, 'The American way of life is not negotiable' (Eilmer-Dewitt 1992, p.42). Subsequently President George Bush Junior and Australian Prime Minister Howard have chosen not to ratify the 1997 Kyoto Protocol aimed at setting targets for the reduction of greenhouse gas production to 1990 levels (or, in Australia's case, eight per cent above that) by 2010.

Despite these two federal governments showing a lack of concern for the consequences of increased fossil fuel consumption, both the US Department of Energy and Environment Australia have established programs to encourage and advise householders to make the largely energy inefficient homes of both countries more efficient and reduce their contributions to the greenhouse gas burden. Largely, however, the design of new homes in Australia remains in the hands of builders and draughtspersons, few of whom 'are familiar with – or concerned about – efficiency of energy use' (Okraglik 1996, p.20). Upgrading the energy efficiency of existing building stock is governed by the interest and financial capabilities of homeowners or renters.

2.3 Advantages of Energy Efficient Housing

. . . let me tell you first about the climate and countryside, and the lovely situation of my house, which will be a pleasure alike for me to tell and you to hear . . . It faces mainly south, and so from midday onwards in summer (a little earlier in winter) it seems to invite the sun into the collonade . . . two collonades, rounded like the letter D, ... enclose a small but pleasant courtyard. This makes a splendid retreat in bad weather, being protected by windows and still more by the overhanging roof . . . Round the corner is a room built round in an apse to let the sun in as it moves round and shines in each window in turn. . . . In front is a terrace scented with violets. As the sun beats down, the arcade increases its heat by reflection and not only retains the sun but keeps off the north-east wind so that it is as hot in front as it is cool behind. In the same way it checks the south-west wind, thus breaking the force of winds from wholly opposite quarters by one or the other of its sides; it is pleasant in winter but still more so in summer when the terrace is kept cool in the morning and the drive and nearer part of the garden in the afternoon, as its shadow falls shorter or longer on one side or the other while the day advances or declines. Inside the arcade, of course, there is least sunshine when the sun is blazing down on its roof, and as its open windows allow the western breezes to enter and circulate, the atmosphere is never heavy or stale (Pliny the Younger, c.95AD).

Clearly some of the pleasures of the living experience in a well-oriented house designed appropriately for its site and climate have been appreciated for a long time. Well before Pliny the Younger extolled the virtues of his Tuscan villa, Socrates (469-399BC) posited the notion of a 'Solar House' (Figure 2.1) showing how to maximize use of the winter sun but stop direct radiation in the south side in summer (Sabady 1978, p.14).

The 'Solar House Con-
ception' of Socrates
1. Solar radiation on the
South face in summer
2. Solar radiation on the
South face in winter
3. Covered terrace
4. Living room
5. Store room as ther-
mal buffer zone
6. Insulating wall to the
North

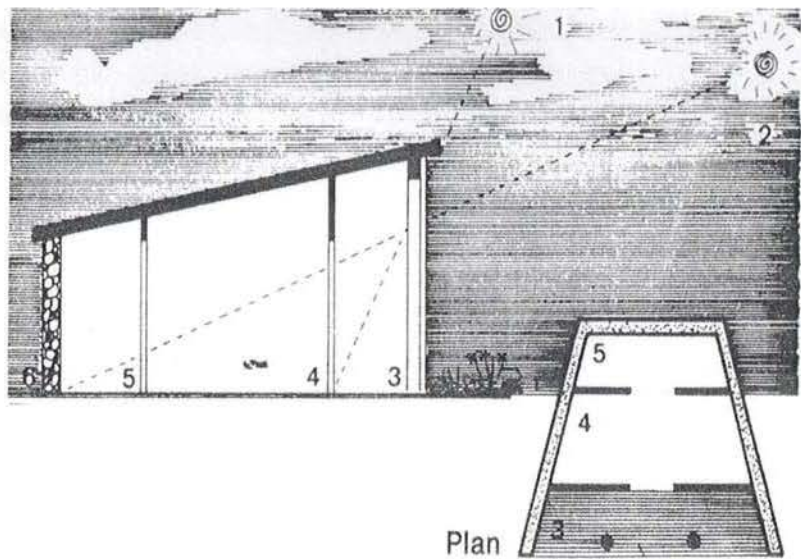


Figure 2.2: Socrates' solar house

Source: Sabady (1978, p.14)

Later, from 919AD to 1180AD, the Anasazi tribe constructed an entire pueblo in Chaco Canyon in a semi-circle facing south to maximize solar input into the living spaces (Figure 2.2). Such an arrangement enabled an entire community to better cope with the rigours of a severe climate. Thus high levels of comfort, the original purpose for all forms of shelter construction, can be achieved more readily and with less artificial energy input requirements, merely by correct building orientation and appropriately located windows.

In western civilization these simple principles were not employed in succeeding centuries of housing construction. Now, after the proliferation of mass-produced housing described in section 2.2, it has become necessary to attempt to retrofit existing homes in an attempt to raise the often exceedingly poor levels of comfort they provide. As building orientation cannot be altered, and adding windows is an expensive and often difficult task, other aspects of the building structure are targeted. In the United Kingdom the Home Energy Efficiency Scheme (HEES) established in 1991 by the *Social Security Act 1990* had improved the draught-proofing and insulation of three million households by 1999, with evidence of improved comfort and high levels of satisfaction (Ekins, Russell & Hargreaves 2002, p.43).

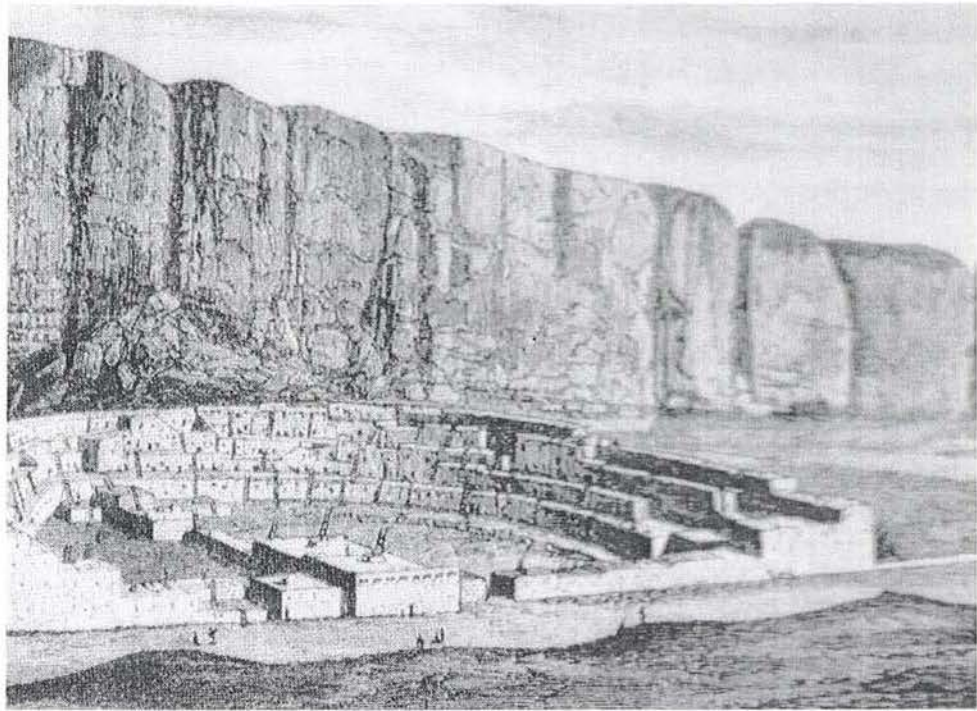


Figure 2.3: Pueblo Bonito, Chaco Canyon (engraving)

Source: Watson (1977, p.2)

Important though comfort is, Anderson (1993, p.20) considers that the most serious arguments for energy conservation are equity issues. Improved residential energy efficiency results in conservation of energy, and hence reduced energy bills. In his Barnett Oration on Sustainability and Housing in Melbourne in September 2002, Professor Peter Newman spoke of how the principle of equity and human rights is sometimes overlooked as one of the foundation principles of sustainable development. Low-income and disadvantaged people spend a disproportionate amount of their incomes on energy (Herbert & Kempson 1995, Pye 1996); are more likely to live in poorly insulated and maintained homes; and are thus unable to afford sufficient energy to heat their homes (Boardman, Bullock & McLaren 1999). Equity issues in home heating have been addressed by some overseas government programs including the British Government HEES mentioned above, which was aimed at low-income, disabled and elderly householders. In 1974, the US Federal Government established the Weatherization Assistance Program as part of the *Community Services Act*. Its aim was to provide draught-proofing and insulation for low-income households especially for the elderly, the physically challenged and children (Pye 1996, p.2). In addition, as Pye notes (p.3) the low-income population effectively faces an on-going energy crisis, and if they cannot pay their bills and are

disconnected from energy supply, in extreme climate situations, or for elderly, the unwell and the very young, this crisis can escalate to an issue implicating their very health and well-being.

The British Government has been conducting House Condition Surveys for decades, with, for example, the Northern Ireland house condition surveys having commenced in 1974 (Northern Ireland Housing Executive 1997, p.3), and published a UK Fuel Poverty Strategy in November 2001. A household was defined as being in fuel poverty if 'in order to maintain a satisfactory heating regime, it would be required to spend more than 10 per cent of its income on all household fuel use' where a 'satisfactory heating regime' was defined as 'one that achieves 21°C in the living room, and 18°C in the other occupied rooms' (Scottish Executive, August 2002, p.5). The 1996 Scottish House Condition Survey found that less than four per cent of Scotland's fuel poor live in dwellings with good energy efficiency ratings (Scottish Fuel Poverty Statement 2001). Healy and Clinch (2002) consider that fuel poverty is possibly the strongest adverse social impact resulting from the inefficient consumption of energy in the residential sector. Australian government currently has a fuel poverty strategy (Sharam 2003, p.10), although a Home Energy Advisory Service (described below) which ran in the mid-1980s in Victoria found that the low-income households targeted spent 10-15 per cent of their income on energy bills (Blackman and Vivian 1985, p.5).

Focusing on the Tasmanian situation, Australian Greenhouse Office figures suggest that on average Tasmanian homes use more than 42 per cent of their energy consumption on space heating, that figure representing the national average (ABS 2002). Furthermore, disposable income/capita in Tasmania is by far the lowest in the nation, 20 per cent below the national average (Madden 2003). Ballinger (1997) reported that by the exclusion of draughts and increasing of insulation in existing houses energy use could be reduced by 40 per cent. For the 40 per cent of Tasmanians for whom income assistance is their primary income (ABS 2001), the disproportionately high amount of their limited financial resources spent on energy bills, if reduced by 40 per cent, could decrease financial stress and improve their quality of life. It should be noted that the figure of 40 per cent possible reduction in energy consumption suggested by Ballinger, and other estimates of up to 65 per cent (Jaccard *et al.* 1996) have been tempered by research such as that of Parker,

Rowlands and Scott (2003, p.174-5) who consider 25 per cent to be a more realistic figure, due to the high cost of some upgrade options. Nevertheless, improved quality of life and decreased financial stress are still to be expected from improved energy efficiency of housing, not just for low-income groups but for all households. The benefits should be most pronounced in Tasmania due to the disposable income per capita being by far the lowest in the nation, at 20 per cent below the national average (Madden 2003). Furthermore Tasmania has the highest proportion of older housing stock in the nation, with 23 per cent of housing built more than 50 years ago (ABS 2000). Analysis of the Residential Energy Efficiency Program database compiled from 3,700 home energy audits in Ontario, Canada showed that pre-1940s houses have the greatest potential for improved energy efficiency (Parker, Rowlands & Scott 2003, p.181).

In addition to financial savings for residents, there can be economic benefits for whole communities when residential energy efficiency is improved. A study done in rural Iowa revealed that each million dollars spent on that state's weatherization program supported 34 jobs and provided about \$685,000 of additional value to the local economy (Pye 1996, p.5). Approximately \$240,000 of these benefits is indirect benefits from increased local spending rather than money being spent on imported energy. These benefits are accentuated in low-income communities as low-income residents are more likely to shop locally, and their local businesses are more likely to use local suppliers than are other larger businesses. Two home energy improvement programs conducted in Victoria generated employment while they ran, and 71 per cent of participants subsequently found other employment (Blackman & Vivian 1985, p. 21). The Home Energy Advisory Service (HEAS) carried out 18,000 energy audits from 1983–85, and the Community Home Energy Improvement Scheme (CHEIS) provided advice and did retrofit work. Both programs were aimed at low-income households with high energy bills (or exceptionally low ones) and were delivered by long-term unemployed people who had been purpose-trained .

Returning to the social consequences for people living in poor quality energy inefficient housing, it is necessary to stress that the quality of the home environment has health implications beyond the level of comfort and pleasure experienced by the occupants. As Burningham and Thrush (2003, p.525) have observed: 'The connection between cold damp housing and rates of morbidity and mortality is well

established.’ Indeed there are some serious disadvantages to living in housing with poor energy efficiency. Not only will such housing aggravate coronary heart disease and stroke, but it is ‘also associated with the presence of condensation, mould and mites which trigger a range of respiratory ailments’ (Huby, 1998). A UK government report on indoor air quality concluded that damp surfaces promoting the growth of mould, bacteria and mites may lead to hypersensitivity with severe reactions including breathing difficulties (Environmental Committee, 1991), with those most at risk being children and the elderly. In a cross-sectional study from a European Community respiratory health survey, sensitization to moulds was found to be a powerful risk factor for severe asthma in adults (Zureik *et al.* 2002). Similarly, a Swedish investigation found a statistically significant correlation between damp buildings and respiratory symptoms in young adults (Gunnbjornsdottir *et al.* 2003). A pilot study assessing 72 children with previously diagnosed asthma in 59 damp houses in Cornwall, compared their health before and after energy efficient retrofits which improved the energy efficiency of the homes by a mean of 2.1 on the National Home Energy Rating scale. All respiratory symptoms were significantly reduced, especially nocturnal coughing, and time off school for asthma declined from a mean of 9.3 days per 100 school days to 2.1 (Somerville *et al.* 2000).

There has been a wide range of studies to determine what constitutes a suitably warm living environment. Isaacs and Donn (1993) found that New Zealand has relatively greater seasonal dependence of mortality than the more severe climates of the UK, US, Japan or Sweden. A possible reason for this can be found in the work of Shannon *et al.* (2003) in their study of room temperatures in winter in student rental housing in a poor quality housing sector of Dunedin. They found that students rarely heated their rooms above 16°C, often tolerating much lower temperatures. Concurrent monitoring of an energy efficiency retrofit program of public housing in southern New Zealand revealed room temperatures strikingly similar to the student housing data, including the extreme situation of one household room occupied at a temperature of just 3°C (Lloyd and Shen 2003). In discussion of cold acclimatization (defined in section 3.3), which requires higher metabolic energy consumption, Folk (1981, p.158) refers to the obvious nutritional consequences of adapting to colder conditions.

An investigation into health standards for room temperature in cold climates in China monitored 205 rooms in coastal and inland areas, involved interviews with 2,401 people and studied physiological indices including blood circulation. It was concluded that while 16-20°C is a comfortable room temperature, winter temperatures could be maintained in the region of 14-16°C, but should not be allowed to drop below 14°C (Meng 1990). In Japan peripheral circulation and sensory tests immersing one hand in cold water at 10°C for ten minutes have been performed widely to diagnose hand-arm vibration syndrome. An investigation into influencing factors found that finger skin temperature was strongly affected by the temperature of the room in which subjects had been kept (Harada *et al.* 1998). These last two studies have implications for the health of people with poor circulatory function living in cold houses, particularly vulnerable groups such as diabetics and the elderly, and all of these studies reinforce the World Health Organization recommendation for room temperatures to be maintained at or above 16°C (WHO 1989). However work by the Building Research Establishment in Britain on a large number of new owner-occupied homes found the average living room temperature to be 19.3°C, which was rated neutral to warm by the owners, suggesting that the recommended 21°C in the UK Fuel Poverty Statement is unnecessarily high (Oseland 1994).

Increasingly there are well-documented examples of the environmental gains available from appropriate design, as well as from energy efficient retrofits to existing houses. As mentioned in section 2.2, since about 1990 there has been increasing concern in the international scientific community about the continuing rise in greenhouse gas emissions and their possible connection with global climate change. The British Government has been running the Home Energy Efficiency Scheme since 1991, and partly as a result of this concern aims to continue with an expanded program of grants to reduce heat loss from homes and improve lighting and heating system efficiencies as well as subsidizing more efficient appliances, with the aim of reducing carbon emissions, as well as fuel poverty (Ekins, Russell & Hargreaves 2002, p.44). Environmental externalities involved in the production of electricity – the mining, transportation and burning of fuels – are not reflected in the retail cost of electricity (Hirst 1991, p.8). Increased residential efficiency reduces electricity consumption and the associated environmental impacts. (Although many Tasmanians would argue that these externalities are irrelevant to them, hydro-

electricity generation is not free of environmental impacts: dams submerge ecosystems and reduce environmental flows in rivers, among other effects.) At the personal level, increasing numbers of residents are choosing to improve the efficiency of their homes to reduce their contribution to these impacts. During the 1990s, for instance, Michael Mobbs and Heather Armstrong needed to renovate the kitchen and bathroom of their inner city 1890s Sydney house, and took the opportunity to investigate avenues to reduce the impact of the house on the wider environment in all ways associated with water and energy use. According to their energy consultant, the retrofit which produced 'The Sustainable House' reduced their annual contribution to carbon dioxide emissions by six tonnes, as well as saving them \$860 annually in energy and water costs at 1996 values, the latter calculated from comparison of bills (Mobbs 2002, p.94). In another case, a retired architect named Derek Wrigley retrofitted an otherwise conventional slab-floored brick veneer house in Mawson, ACT, with a strong focus on sustainability and reducing environmental impacts associated with energy and water inputs. He considers he has achieved annual savings of 6.8 tonnes of carbon dioxide and over \$1700, the latter from estimates of reduced heating and cooling requirements (Wrigley 2004, pp. 13-2 to 13-4).

The residents of these homes are not so captured by the global significance of what they have achieved that they fail to notice the local gains. They also speak of the much improved living experience in the altered house: '... we have ended up with a modern, easy-to-live-in terrace house that gives us a lot of pleasure' (Mobbs 2002, p.19); '...a livable, comfortable house ...' with 'year round comfort for the occupants ...' (Wrigley 2004, p.2-5). Pliny the Younger would be pleased for them.

Much of the focus on evaluating the advantages of energy efficient housing and retrofitting to achieve them has been directed at assessing the financial gains in terms of reduced energy bills (Claridge 1994), the subsequent payback period to justify it (Petersen 1974, Coulson & Thompson 1981)), or aimed at quantifying the environmental benefits in tonnes of greenhouse gas emissions avoided (Ekins, Russell & Hargreaves 2002). However, some of the potential energy savings achieved by a retrofit are often taken back in the form of increased thermal comfort, and the lower the original room temperature the higher the 'takeback' (Milne and Boardman 2000, p.411). Takeback reduces the apparent gains from the retrofit if economics are the

sole measure of success. The advantages of energy efficient homes include many immeasurables. It is difficult attempting to assign monetary value to the health of people in energy efficient homes, the greater feeling of year round comfort or the happier living experience – how it feels to come home to such a place. Furthermore, energy efficient homes require the burning of less wood, the fuel used for space heating in many older, less efficient homes in Tasmania, so there can also be gains in outdoor air quality, as modelled by Lo, Norton and Mannis (2000) in their case study of domestic energy use and air quality in Belfast. Thus, even people who already live in energy efficient homes can benefit from improvements made to the inefficient ones around them.

2.4 Why Has It Not Happened?

Why has energy efficient housing not become a social priority – a priority of governments and the people? Some authors have suggested that energy efficiency improvements can yield sufficient savings to make it equivalent to a new source of energy (Lovins 1977, Hirst 1991, Clarke 2001), capable of delaying the need for energy supply expansion. In 1989, for example, the Swedish State Power Board, Vattenfall, published a thorough technical study which found that if the country used mid-1980s energy efficiency technologies, it could save half of its electricity at an average cost 78 per cent lower than that of making more (Hawken, Lovins & Lovins 2001). If these savings are possible in a country with abundant energy-intensive industry, clouds, cold, and already amongst the world's most energy efficient, Australians should be able to make even more impressive advances.

Reasons for the lack of uptake of energy efficiency measures are complex, and the first one may relate to the nature of energy supply institutions with their long lead times to bring new plant on-line, and the rational planning decision making process under the pressure of uncertain demand. In a model proposed by Collingridge (1980), once a forecast for demand is accepted, a proven technology is chosen by the energy supplier and a large unit constructed to capture economies of scale. Once new supply comes on-line, the supplier needs to encourage consumption to cover debt (rendering the forecast a self-fulfilling prophecy) and then has no interest in promoting conservation of energy until demand eventually begins to approach supply capacity, at which stage a public conservation strategy may buy time for the supplier. Even

then energy conservation is not relied on due to uncertainty about its efficacy (it not having been tried before) so a decision is made quickly to expand supply again. In this regard Harries (1996, p.142) cites Puiseux (1987), an econometric modeller with Electricite de France, who considers that the situation is exacerbated by the asymmetric risks of over-supply (over-capitalising) and under-supply (power blackouts). The former is perceived as preferable to planners for security of supply, so the tendency is to adopt high load forecasts to avoid the potential disasters of the latter. Once tenders for the expansion have been called, the supplier's focus immediately shifts away from energy conservation to ensure sufficient demand for the large new increment of energy supply, until such time as planning commences for further supply expansion (Harries 1996, p.145). Furthermore the states and territories in Australia have few avenues open to them to generate employment, save the exploitation of their natural resources. In Tasmania, cheap hydro-industrial power has enabled government to attract industries which then provide jobs and contribute to economic growth (Crowley 1989, p.48), an approach which has had multi-lateral political and bureaucratic support. This close tripartite relationship in Tasmania, in addition to the vested interests of the supply institutions, has thus far collectively reduced the likelihood of energy conservation measures being implemented. Tasmania has traditionally had a strong engineering culture in the field of energy supply, and in such a culture 'grand engineering supply projects such as large dams . . . or wind farms are a more appealing option than the attempt to decrease energy use through the encouragement of lots of small and relatively drab measures such as constructing pelmets over windows, insulating attic spaces, or replacing refrigerators with more energy efficient models' (Harries 1996, p.160).

Previous oil crisis events during 1973-4 and 1979-80 produced an upsurge of interest in energy conservation and the need for energy efficiency measures in the scientific community and at government level in all industrialized countries (Challen *et al.* 1983, Parnell and Cole 1983). The first crisis caused a reduction in growth of consumption of oil in the United States of 58 per cent and the second caused consumption to shrink, resulting in so much excess supply that oil prices dropped and consumption rose again (Hawken, Lovins & Lovins 2001, p.253). The US Federal Government initiated the Weatherization Assistance Program in 1974, as described in section 2.3, and in 1980 commenced the Home Energy Assistance Program (later re-named the Low-Income Home Energy Assistance Program) to

reduce the energy burden of eligible households and avoid disconnections. Funding for both programs is declining, and after major cuts to the latter in 1987-9 disconnections doubled (Pye 1996, pp.2-3). Similarly home energy efficiency programs instigated by the Australian Federal Government after the second oil crisis (Parnell and Cole 1983) were not maintained when the crisis was perceived to have ended, and no national campaign to improve residential energy efficiency was run in Australia until the establishment of the Australian Greenhouse Office in 1998 and the campaign to reduce greenhouse gas emissions. A campaign to improve residential energy efficiency in order to reduce the risk of global climate change can be too indirect in approach. People feel that the major factors controlling energy-using behaviour operate at the societal level, so they are not easily altered by individual action (Crossley 1980, p.2). The current high oil prices (\$55/barrel in October 2004) should have no impact on residential energy efficiency planning as Australia's electricity is derived from the burning of coal.

Overseas, a range of studies on the social factors impeding the take-up of energy efficiency measures after the second oil crisis appear not to have been acted on in subsequent campaigns. Research by Kahneman and Tversky (1979) and Yates (1982) indicates that people respond more seriously to a loss than they do to a gain. Thus the conventional approach of emphasising the gains that people could make by making their house more energy efficient may have less appeal than focusing on the money they are wasting on a daily basis by not doing it. Hutton and McNeill (1983) have noted that conservationists had been slow to recognise differential responses by consumers to conservation policy, products or options. They made the point that, as with any other consumer products, it is necessary to have a targetted marketing strategy which recognises market segmentation – there are groups within society which have identifiably different characteristics (amongst others they list income, education, ethnicity, age). The members of these groups have different desires and needs. Nevertheless, Aronson and Yates (1983, p.16) contend that most people will be more strongly influenced by the report of a single neighbour who has successfully adopted an innovation than by a media campaign. They note that such 'social diffusion' methods are more effective than media at inducing the take-up of new behaviours, a point reinforced by Katz and Morgan (1983, p.232) who also suggest the value of using a local home to run a demonstration workshop showing how improvements are made. Hutton and McNeill (1983) also found that psychological

and attitudinal variables were important, and that, for example more conservation actions were taken by households whose political ideology was more liberal.

Lifestyle decisions may be significant in residential energy consumption. In an early study into lifestyle and controlled technology, Socolow (1975, p.320) found that people varied greatly in their use of gas and electricity:

We have found wide variation in consumption of both gas and electricity, both in winter and summer, in nearly identical townhouses. The more a technology allows expression of individuality the more the expected variation, so that indeed there is more variation in summer electrical consumption . . . than in winter electrical consumption and more variation in the latter than in gas consumption for the winter. But even the variation in gas consumption for winter heating is substantial.

Later, Knutson (1983) reviewed energy-lifestyle literature and found an overabundance of lifestyle variables due to a lack of attention of many researchers to validating the lifestyle measures, as well as a heavy reliance by energy-behaviour researchers upon demographic variables to identify lifestyle profiles. She proposed that energy-behaviour researchers emulate the lifestyle models of consumer marketing research, grouping the variables as illustrated below (Figure 2.3). Lifestyle could be defined as “a role-related phenomenon which is the specific or characteristic manner of expressing beliefs, attitudes, and values through the acquisition and allocation of resources” (Knutson 1983, p. 514).

Knutson considered that the range of variables from previous studies, as illustrated above, needed rationalizing. However, even if rationalized, the complexity of social factors implies that a simple broad message of the value of energy efficiency has little chance of garnering widespread support. Illustrating that, Parker, Rowlands and Scott (2003, p.173) describe how the Canadian Government adopted the R-2000 Program for cost-effective energy efficient building practices and technologies based on a well-sealed building envelope in 1982. Its take-up is estimated at 0.7 per cent of the new houses built from 1990-1996.

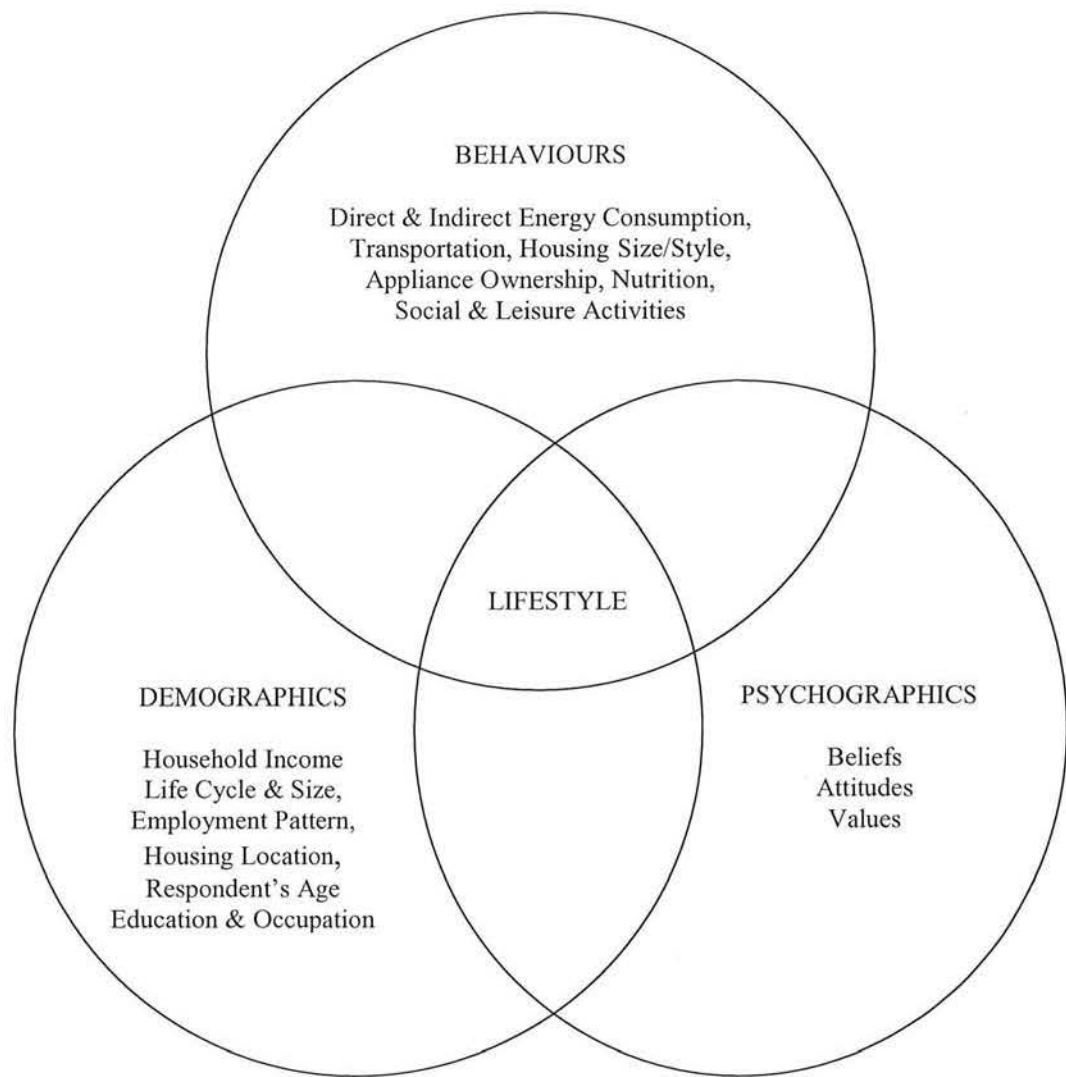


Figure 2.3 The three primary determinants of lifestyle
(adapted from Knutson 1983, p.516-7)

Energy efficiency campaigns that have been run in the past may have only appealed to a part of the social spectrum for a range of reasons, which could include association only with a time of crisis, or emphasising gains to be had rather than everyday losses. Strategies may have appealed only to those already concerned, or not appealed to those who couldn't afford to make changes; they may have inspired people with a technical interest or been founded on concepts too esoteric for groups coping with daily struggle. In a study of non-technical barriers to energy conservation by householders in Victoria, Crossley (1981, p.44) identified such 25 barriers which fitted into six groups. Three barriers arose out of economic cost, four from inadequate information, and only one from structural factors – inadequate provision of goods and services. The remaining 17 barriers were attributable to social, personal, attitudinal and lifestyle factors. He observed how often policy makers focus on macro-issues and have considered legal/regulatory barriers to be

most significant (p.85). Crossley also conducted a study in Brisbane to investigate the social factors affecting energy use and conservation in the home and found a lack of correlation between beliefs (and the attitudes they informed) and energy-using behaviour (Crossley 1980, p.101). He considered that the attitude-behaviour gap could be because the interactions between energy and social structure at the societal level may define individual domestic energy use in industrialized nations (p.109). To Crossley, the two sets of salient factors were the overall magnitude of energy use in the society and the socio-economic status and institutional constraints and incentives operating on the individual.

Parker, Rowlands and Scott (2003, p.181) suggest that to be effective across the whole of society an energy efficiency campaign needs to adopt an integrated approach. They present the success of the national Residential Energy Efficiency program in Waterloo, Ontario, Canada which commenced in May 1999 as a model for an effective way to run a campaign, and consider its success to be due to four factors absent from conventional campaigns. Firstly instead of aiming for the maximum technical potential to reduce energy demand, they adopted a more considered socio-technical estimate which factors in social limitations such as attitudes and behaviour of residents. Secondly they used local delivery agents who produced local motivational materials to enhance delivery of the national campaign. Thirdly, the local capacity developed by a diverse range of local, state and federal agencies and local businesses facilitated program delivery. Finally the campaign was enhanced by a survey of residents' attitudes in comparison to behaviour. The personal contact form of approach aimed to empower behaviour change by identifying benefits and providing a practical course of action for residents (p.173), and resulted in a substantially greater proportion of people having home energy audits than for the rest of Ontario. In an earlier analysis of the Waterloo project, Kennedy *et al.* (2000, p.60) describe the technique that was used to impart the message in the campaign as social marketing, in which the ultimate goal is primarily to benefit not the sponsoring organization, but instead the target audience (consumer) and broader society. This case study appears to contain some vital local community ingredients lacking from the broader national campaigns of Australia.

In Tasmania, for the reasons presented, there has not been and is unlikely to be a State government sponsored campaign to directly encourage all households to

improve the energy efficiency of their homes in less than a time of crisis. The unlikelihood of such a campaign is illustrated by the situation in times of prolonged drought when it becomes necessary to bring the Bell Bay Thermal Power Station on-line to supplement energy supplies from low-level reservoirs. The State government publicizes the imminent event, the time it takes to ready the plant and its expense to run, but does not take the opportunity to campaign for improved energy efficiency in the public sector, even though some of the major industrial consumers occasionally reduce production to ease the situation. The Federal Government's efforts towards promoting residential energy efficiency are confined to the work of the Australian Greenhouse Office, and the Cool Communities program with their appeals to reduce greenhouse gas emissions may be too esoteric to be effective for many Tasmanians. With most residential energy in the State currently coming from hydro-electric sources, such emissions are not involved in residential energy consumption except when Bell Bay is operating. It is widely accepted within the state that Tasmania has 'green power' and even when Bass Link connects Tasmania to the national grid through the Bass Strait undersea cable in late 2005 there may be an unwillingness to appreciate that the situation is changing. Victoria had an aggressive Demand Side Management program in place to improve energy efficiency in the 1980s, but a change of government and a restructure towards competitive market reform and privatisation of energy supply saw that scrapped (Harries 1996, p.306). The Bass Link connection could make top-down energy efficiency campaigning even less likely to occur in Tasmania.

Thus any truly effective energy efficiency campaign directed at Tasmanian householders needs to be conducted at local government level, with the integrated approach of the one at Waterloo. Currently (November 2004) there is only one local government running an energy efficiency campaign in Tasmania. Hobart City Council has produced a checklist of energy efficient design criteria for new homes, and applicants submitting a plan which incorporates sufficient of the criteria receive a 50 per cent rebate of their building application fees. In addition Council has produced a booklet of energy efficient design guidelines in conjunction with the Housing Industry Association (HCC 2003). These measures will only reach some of the two per cent of people in any year who are building a new home – those who choose to satisfy the design criteria beyond the mandated requirements, and whose building site allows them to. They would need to understand and relate to the concept

of the benefits of good design as detailed in the booklet, for the financial incentive of the rebate is negligible compared with the construction costs.

For the remaining 98 per cent of people living in existing housing in Tasmania there is no on-going residential energy efficiency campaign. News items and documentaries on climate change and global warming slowly increase public awareness of potential damage from fossil fuel consumption. On the mainland Mobbs and Wrigley (in section 2.3) have been concerned at the need to reduce ecological footprint, so concepts of sustainability, intergenerational equity and reducing greenhouse gas emissions appeal to them, as they would to a proportion of Tasmanians. However, Burningham and Thrush (2003, p.534) concluded from a study of disadvantaged groups that people are unlikely to feel motivated to consider larger environmental issues when they face basic problems of fuel poverty, damp houses and poor health within their immediate environment. The needs of such groups, for example, should be ascertained and an entirely different campaign run to assist them to improve their situation than would be appropriate for non-disadvantaged groups. While conservationists and environmentalists have been criticized overseas for not being close enough to the people and the issues in housing (Keenan 1995), or for not recognizing market segmentation (Hutton and McNeill 1983), it is not those groups alone who are responsible for designing energy efficiency campaigns. The residential energy efficiency programs run overseas (described in section 2.3) have been distinctly lacking in Australia, and it would appear that the eminently worthwhile cause, energy efficient homes for one and all, has lacked a champion in Australia and in Tasmania.

2.5 Summary

The mass-produced housing stock of the decades since World War II bequeathed to the residents of the new millennium was not built by the people for the people, but has increasingly become a commercial product, commercially designed and marketed. Age-old concepts for solar homes have been further researched and developed in parallel with the mainstream market. Well-designed homes have remained the choice of few rather than available to all because it suited the building industry, planners and developers. Energy efficient homes offer significantly better living environments in terms of comfort, health and safety, are appreciably less

expensive to warm and cool, and their operation has reduced impact on the global environment. Decreased health problems for the residents of such homes would reduce national health bills. Existing buildings can be retrofitted to achieve many of these advantages. Nevertheless programs to capitalise on all these possible gains have been sporadic (at times of oil crises), unsustained (funding is gradually withdrawn), poorly marketed (ignoring market segmentation) and above-all the vested interests of energy providers and bureaucracies have kept them off the agenda in Tasmania. Despite these shortcomings, there is increased social awareness of environmental and energy issues, but people fail to, or are limited in their capacity to act on their knowledge for a range of reasons: financial disadvantage, personality factors, or the gap between attitude and behaviour due to social factors. To deliver energy efficiency improvements effectively will require the development of multi-lateral, multi-level capacity-building partnerships in ways which will be described later in this study. First in Chapter 3 it is necessary to describe and analyze the principles which govern the movement of heat into and out of buildings, in order to find ways to alleviate some of the problems associated with poor quality housing.

During the following year, having lived with the heat beating through the roofing iron on the hot days, and the chill of the cold nights, I insulated the ceiling of the new extension as I nailed up the ceiling timbers. Another topic which had captured my interest in physics classes at school was heat transfer. Insulation seemed to make such good sense. I don't recollect the R-values of the batts I used in the ceiling, although I'm certain I would have used thicker ones if I were doing the work now.

I worked in the city and only really lived in my new home on weekends and in holidays, (although on the long summer evenings I put in considerable hours after work, at the task of clearing about an acre of blackberries). It was a treat to light huge fires in the two massive fireplaces in winter, but I noticed that they did little to warm the air in the rooms. This mattered little to one so young, active and enamoured of the property. I was to learn, in the course of writing this thesis nearly 30 years later that age and activity level are some of the factors which can influence one's perception of thermal comfort. The benefits of the 25 centimetre thick mudbrick walls were, however, not lost on me, especially in summer. The original cottage stayed delightfully cool in the inevitable long heat-waves, and after hot nights I arrived at work refreshed and the envy of my Adelaide plains-dwelling colleagues. The cellar I dug under the new sunroom before I installed its floor worked well too, and became a vital retreat on the fierce days at the end of the longest hot spells. Later the lined curtains I put in the sunroom helped exclude summer heat and retain winter warmth. Not until the fourth summer, after having the original part of the house re-wired, did I remove a few sheets of iron, enter the roof space and retrofit the original ceiling with insulation batts. This made the best-insulated part of the house even better. I used to cover the chimney-tops in spring to keep the flies out, which also reduced the flow of hot summer air through the house. Lighting the first fire in autumn usually resulted in a frantic dash to the roof.

CHAPTER 3: RETROFIT PRINCIPLES

3.1 Introduction

Retrofitting techniques can be classified according to the form of heat transfer which they aim either to reduce or increase. In this chapter I begin by investigating the physics of heat transfer as it relates to the elements of a building and the operation of a whole building. As the major expectation of people is that their residence will provide some degree of comfort, a review of the contrasting approaches to the study of thermal comfort is then made, followed by an analysis of the implications some of these approaches have for energy consumption in the home.

3.2 Heat Transfer

Heat flows into and out of a building by any one of, or combination of, three mechanisms: radiation, conduction, and convection (Croy and Dougherty 1984, p.7).

3.2.1 Radiation

Radiation is the form of heat transfer in which heat passes from hotter objects to cooler ones without the involvement of a medium. Heat radiation is electromagnetic radiation, like light (Croy and Dougherty 1984, p.7). A notable example is the transmission of heat energy from the sun to the earth. Radiation rates are also affected by the surface properties of the objects involved. According to the theory of black-body radiation, a black body is an ideal object which absorbs all radiation incident on its surface, and is able to re-radiate all that energy (Ballinger 1997, p.50). Absorptivity (α) for a material is the ratio of thermal radiation absorbed per unit area of its surface to the thermal radiation absorbed per unit area by a black body. Absorptivity is colour dependent, and for a matt black surface $\alpha = 0.91$, making surfaces of that colour in a house excellent heat absorbers when exposed to sunlight. Emissivity (ϵ) refers to the ability of a surface to give off heat, is similarly defined with reference to a black body, but is unaffected by the colour of a painted surface (Ballinger 1997, p.53). The reflectance (r) of a surface is the ratio of reflected radiation to incident radiation. Aluminium is a good reflector ($r = 0.9$) but a poor

emitter ($\epsilon = 0.05$), while white paint is a good reflector ($r = 0.8$) and a good emitter ($\epsilon = 0.9$).

Of additional importance to heat transfer in buildings are the properties of glass. Solar radiation is classed as short-wavelength radiation, and glass is transparent to it, with normal 3mm window glass transmitting 87 per cent of the incident solar radiation. However glass is opaque to the re-radiated longer wave radiation from heated objects within the building, giving rise to the Greenhouse Effect (Greenland & Szokolay 1985, p.25), which can be a valuable contributor to space heating in homes during daylight hours in winter, as well as a source of overheating in summer. Energy can still be lost from within the building by conduction through the glass, and by radiation at night, particularly in winter. Pratt (1981, p.22) found that radiant heat loss through windows could be reduced by 19 per cent by lightweight curtains, and by 27 per cent by heavy ones.

Within a living space dark coloured surfaces with their high absorptivity are good for collecting incident solar radiation during the day and re-radiating it at night, so they are preferred for floors and walls exposed to sun in winter. Curtains should be left open during the day to admit radiation and closed at sunset to minimize radiation heat losses.

3.2.2 Conduction

Conduction is heat flow within a solid from a region of high temperature to one of lower temperature through molecular action. The rate of heat flow is proportional to the size of the material through which it is flowing, the distance it has to travel, the difference in temperature, and the thermal conductivity of the material (Sears and Zemansky 1964, p.321). Thermal conductivity is measured in $W/m^{\circ}C$ where W is in watts. (The actual heat flow rate through unit area of a given thickness of a material is called its thermal conductance, C, measured in $W/m^2\ ^{\circ}C$.) Metals have very high conductivity (steel 47.5, aluminium 220 $W/m^{\circ}C$), whereas heavy building materials (brick 1.42, concrete 1.44 $W/m^{\circ}C$), while not being good conductors, are not particularly good at resisting heat flow. On the other hand wood (0.10-0.15 $W/m^{\circ}C$) is an order of magnitude poorer at conducting heat, and the materials used to insulate buildings have conductivity values another order of magnitude lower (rockwool and

glass fibre 0.034W/m°C). Dry air with a value of 0.024 at 10°C is the basic operative of these materials (Ballinger, Prasad & Rudder 1997, p.55).

When discussing how a material contributes to the thermal behaviour of a structure, the property most commonly used is that of *thermal resistance* (R), which is the reciprocal of thermal conductance ($R = 1/C$). The thermal resistance is usually referred to as the R-value of the substance, and is measured in $\text{m}^2 \cdot ^\circ\text{C}/\text{W}$, where W is measured in watts. The R-value indicates how well a given thickness of a material resists heat transfer. The higher the R-value, the less heat flows through it, or in other words the better insulation the material provides. If different materials are in contact with each other, their combined thermal resistance is the sum of their individual R-values. Air films on the surfaces of building elements contribute a surface or boundary resistance, which is generally quite low on the external surfaces, and not much higher (about R 0.1) on high emissivity internal walls, although it may be as high as R 0.3 to R 0.56 on low emissivity ones (Ballinger 1997, p.56). Trapped air spaces between building materials increase the overall thermal resistance, although the thermal resistance of an air space depends to different degrees on several factors. As most building materials have high emissivity in the range $\varepsilon = 0.90\text{-}0.95$ (Greenland & Szokolay 1985, Ballinger, Prasad & Rudder 1997), radiation accounts for over 60 per cent of heat transfer across an air space. The thickness and orientation of the space affects the modes of heat transfer, with direct conduction responsible for about 30 per cent of total heat transfer across a 12mm wall cavity, decreasing to a negligible proportion across large spaces (Pratt 1981, p.287). Convection is minimal across a 12mm wide vertical space, but increases to about 20 per cent at 50mm, so if a panel of double-glazed window has the panes of glass too far apart it is possible that a convection current will be set up in the air space and will transfer heat from one pane to the other. A horizontal air space, like that above a ceiling, has higher resistance to downward than to upward heat flow, also due to the establishment of convection currents in the latter case. Ventilation of a roof space will also reduce its thermal resistance.

The selection of appropriate building materials can contribute greatly to reducing the heat losses from a building, or excessive heat gain. As mentioned above, most conventional insulation materials such as fibreglass batts have been manufactured with tiny trapped air spaces in them, providing their thermal resistance. The

effectiveness of insulation batts can, however, be greatly reduced by moisture that fills the trapped air spaces. At 10°C water has a thermal conductivity approximately 25 times that of dry air (Pratt 1981, p.45). Moisture may enter from the outside of the building by leakage of precipitation in through walls and roofs, or it may enter from the leakage of warm moist air from within the house into the wall cavity or ceiling space. In the latter case, this air then becomes chilled and unable to retain its high moisture content, which condenses as small droplets. This problem is common in cold climates and is remedied by installing a vapour barrier (which also has a reflective surface to reduce radiant heat loss) between the inner wall or ceiling and the insulation. Tasmania's climate is generally deemed to be not quite sufficiently cold to require this (Todd, pers. comm. May 2003), so the reflective foil vapour barrier is generally placed between the outside wall or roof and the insulation. The reflective foil is installed with its shiny side facing outwards, and in a roof has a greater resistance to down heat flow (summer) than to up heat flow (winter), because it resists radiant energy flow better than conductive flow (Coulson & Thompson 1981, p.6).

Aluminium window frames can be a substantial source of heat loss because of the excellent conductivity of aluminium, which readily transfers heat from inside the house to outside by forming a 'thermal bridge' (Greenland & Szokolay 1985, p.27) across the wall. To some extent thermal bridging occurs in timber-framed roofs and walls, as structural timber has a lower R-value than the insulation which is placed adjacent to it. The R-values of a range of building materials can be seen in Table 3.1.

It is most important to exclude water from leaking on to insulation as this negates its high thermal resistance. Aluminium window and door frames have become common but thermal bridging is a problem with them. It is possible to buy frames constructed with a break between inner and outer surfaces to reduce bridging, but they are considerably more expensive.

Table 3.1: Typical R-values of some building materials		
MATERIAL	Thickness(mm)	R value (m².°C/W)
INSULATION:		
Cellulose fibre	50	1.3
	100	2.6
Fibreglass batt	70	1.3
	110	2.0
	125	2.5
MASONRY:		
Bricks	110	0.09-0.15
Concrete bricks	110	0.07
WALL CLADDING:		
Weatherboard	9.5	0.05
ROOF CLADDING:		
Metal		0.16 for trapped air space*
Tiles – burnt clay	16	0.01
FLOORING:		
Carpet		0.22-0.37
Cork tiles	6	0.14
Linoleum	3	0.01
Vinyl tiles	2	0.003
Timber - softwood	19	0.17
Timber - hardwood	19	0.10
Sources: Coulson and Thompson (1981, p.5), * Pratt (1981, p.67).		

3.2.3 Convection

Convection is the process of heat transfer from one place to another by the physical movement of a liquid or a gas (Sears & Zemansky 1964, p.322). An example is the way in which warm-air heating systems use air to remove heat from warm surfaces and carry it to the space to be heated. If the heated air is moved by a fan or pump, it is called forced convection. When the movement is due to differences in density, it is called natural convection. These forms of convection provide the basis for two

different forms of solar house heating systems. In both, air or liquid is heated by solar radiation within a confined space, and in the former it is then moved elsewhere in the building by fan or pump to either transfer its heat or for storage of that heat. Such a design approach is called an active solar system. If the air or liquid moves by natural convection, it is known as a passive solar system. Natural convection is often referred to as 'the thermosyphon effect' (Clarke 1979, Parnell & Cole 1983), and is the method by which, for example, a solar hot water heater panel heats water and stores it in a tank elevated above the panel.

When a room is heated, the warmer air, being less dense, rises by free convection to collect at the ceiling, leading to stratification of the air. The heated air can be transferred to an unheated room through a vent high in the wall, while cool air from the latter room is returned to the heated room through a vent near the floor, setting up a convection loop.

On a cold night a convection loop can be driven by the windows. Chilled air on the inside surface of the glass falls to the floor and warmer air from the ceiling adjacent to the window falls down to replace it. Such a loop establishes even more effectively with loose-fitting curtains set out from the wall. Curtains need to fit closely to the sides and bottom of the window frame and have a pelmet over the top to exclude air movement and create a trapped air space (Ballinger, Prasad & Rudder 1997, p.81), increasing the effective thermal resistance of the window (see 3.2.2).

Convection is a driving force for a major source of heat loss from buildings – draughts. Uneven heating of the earth's surface creates convection currents, or winds, which force their way into cracks bringing cold air in on the windward side of the structure and removing warmer internal air through gaps on the leeward side (Pitts and Willoughby 1992, p.202). Landscaping plants can be used to reduce wind impact and infiltration (Olgyay 1963, Coldicutt *et al.* 1983, Pitts & Willoughby 1992). Even when it is calm, internal convection can cause draughts as warm air in the house rises, escapes through cracks around ceiling scotias or out wall vents or chimneys in older homes, and cooler outside air moves into the house through other gaps to replace it. Draughts will be discussed in greater detail in section 4.2.

3.3 Thermal Comfort

A key target in the operation of a home is to achieve satisfactory comfort levels throughout the course of the day and the year. One of the first modern scientists to comment on the influences on human comfort was the German researcher J.T.F. Hermans who suggested in 1883 that thermal discomfort was due to the contribution of excessive temperature and humidity, which was confirmed experimentally in 1905 by Flugge and his associates (Rhee 1986, p.18). Discomfort can also be caused by other combinations of temperature and humidity. Thus matters of thermal comfort fall into the domain of psychrometrics, the study of the thermodynamic properties of moist air, and the use of these properties to analyse conditions and processes which involve moist air (Ballinger 1997). In 1923, Yaglou was the first to use the psychrometric chart (a graphical representation of the thermodynamic properties) as a base for defining two new terms: 'Effective Temperature' (ET) and 'comfort zone'. ET was defined as an 'arbitrary index' combining into a single value the effect of dry bulb temperature, humidity and air movement on the sensation of warmth or cold experienced by the human body. The numerical value is that of the temperature of still, saturated air which would induce an identical sensation. The comfort zone was defined, after testing 130 volunteers in a temperature and humidity controlled room, as the range of effective temperatures within which over 50 percent of the people were comfortable (Rhee 1986, p.18). Yaglou collaborated with Houghten and others over an extended period investigating human physiological responses to different clothing, rates of air movement and other physical factors. The engineering approach to thermal comfort research continued in the 1940s and 1950s, with the literature focused on physiology and instrumentation, living in the tropics and the increased use of Heating, Ventilation and Air-Conditioning (HVAC) in commercial buildings (Riordan 1992, p.9). Rhee believes that there are two shortcomings in using effective temperature as an index for thermal sensation – it over-emphasises the importance of humidity and disregards mean radiant temperature (Rhee 1986, p. 22). Mean radiant temperature is the weighted average temperature of all the exposed surfaces in a given space – weighted according to the angle they make with a person in the space (Ballinger, Prasad & Rudder 1992, p.37). Thus the chilling contribution of a large, cold, uncurtained window at night in a room has no impact on effective temperature, but it lowers mean radiant temperature in a way that approximates how it would be noticed by a person.

In the 1960s and 1970s there was a rise in climate chamber studies, initially under Fanger at Kansas State University, in which large numbers of male and female subjects were studied to see the effects of exercise, clothing and environmental conditions on thermal comfort, which led to an amended effective temperature scale (Macfarlane 1978, p.86). Fanger suggested (1972, p.14) that the chief reasons for creating thermal comfort are to satisfy the desire for people to feel thermally comfortable, to maximize human performance at work tasks, and for optimal human health. Following extensive experimental work he developed a complex comfort equation, which yielded an optimal temperature of 25.6°C for human comfort for $\text{clo}=0.6$, where clo is a measure of the insulation due to clothing worn at the time. One clo is approximately equivalent to a suit (a thermal resistance of about $R\ 0.155$) and 0.5clo is equivalent to shirt and trousers or blouse and skirt (Marsh 1979, p.5). In comparison with Fanger's optimal temperature, the World Health Organization suggests a minimum value of 16°C as a requirement for good health (as referred to in section 2.3). The variables in Fanger's equation are air temperature, humidity, mean radiant temperature, air velocity, clothing insulation and activity level, and the equation was produced from observations of many subjects in a controlled, artificial situation. He did show correlation between his comfort equation and the results of field studies in the arctic and the tropics, but only in terms of predicting a neutral temperature at which people feel comfortable, rather than a range of acceptable temperatures. He considered that he had proven that most people with the same clothing and activity levels prefer the same neutral temperature (plus or minus a degree) irrespective of their sex, age, culture, race, season or climate zone.

Rhee (1986), however, notes that environmental comfort is a highly subjective state and involves an individual feeling that conditions match their personal comfort zone. He feels that this comfort zone is a complex product of physical factors such as air temperature, relative humidity, radiant temperature, air velocity and lighting levels, as well as a range of psychological factors noted by Rohles, Bennett and Milliken (1981, p.527), who found that carpeting, furnishings and acoustic tiles added to a person's perceptions of warmth in a space. In addition, Rhee also considers that parameters of comfort do vary between cultures, regions and across the seasons (1986, p.2). In an attempt to clarify the complex interrelationships, Rhee constructed a conceptual model partly derived from the work of Marans (1981) in his evaluation

of office environments. Rhee's model suggests (p.85) that office workers' perceptions of environmental comfort depend upon six sets of various factors:

- (a) the physical environmental conditions mentioned above;
- (b) job and personal characteristics, including age, sex and type of work;
- (c) physical characteristics of the space;
- (d) individual consciousness of energy conservation (including both general understanding of energy issues and personal conservation efforts);
- (e) personal knowledge of comfort – perceived temperature and conceived comfort range; and
- (f) an individual's health and behaviour.

It is reasonable to expect that similar sets of factors apply to residential occupants.

In an attempt to determine how reducing physical environmental conditions below commercially accepted levels affected office workers, Rhee surveyed workers in an office-block during winter before having the air temperature and air velocity lowered, as well as making changes to relative humidity. Analysis of a subsequent survey revealed that "The only change of environmental conditions which had significant influence on the change of thermal comfort was the change of mean radiant temperature" (Rhee 1986, p.143).

A measure of the importance which attaches to mean radiant temperature is shown by the Australian Department of Primary Industries and Energy preferring to use a weighted radiant temperature, in its definition of environmental temperature, to define comfort zones (Ballinger, Prasad & Rudder 1992, p.39):

$$T_e = 2/3 T_r + 1/3 T_a$$

Where: T_e = environmental temperature
 T_r = mean radiant temperature of surfaces enclosing space
 T_a = air temperature (dry bulb temperature)

In practical terms, the effect of having, for example, the large, cold, uncurtained window, described above, in a room in winter is to substantially lower the mean radiant temperature of the room, resulting in a major drop in the perceived environmental temperature. Occupants may experience this as a shift in conditions

out of their comfort zone. Furthermore, Boje et al. (1948) found that six hours per day exposure for 15 consecutive days to radiant cooling on one side of the body resulted in a thickening of cutaneous and sub-cutaneous tissues and increased tension and soreness on that side of the body. Elderly or disabled people exposed continuously to uncurtained windows could suffer asymmetric circulation problems.

Unlike the reductionist scientific approach of the climate chamber thermal comfort researchers, Rhee's workplace research stands nearer the work of a smaller group including Olgyay, whose work 'Design with Climate' (1963) approaches the design of buildings in ways which enable them to respond to the local climate so they better suit the thermal comfort requirements of their occupants. With his 'bioclimatic' approach he was the first to define the comfort zone in architectural terms (Auliciems and Szokolay 1997, p.56).

The majority of this group of researchers into thermal comfort conducted field studies of people in normal domestic or working environments. Humphreys (1975, p.20) reviewed over thirty such studies and derived relationships between mean neutral temperatures and mean external temperatures, without the need to specify clothing or activity levels. His work opened the way for a more flexible approach to the attainment of thermal comfort. He related the story of the occupants of an unfinished bedroom sleeping comfortably through an unexpected blizzard that covered their beds with snow, which he suggests 'casts doubt on the need for a bedroom temperature of not less than 15°C!' (1992, p.4).

In general the domestic situation is different from the workplace, where heating and cooling costs are considered to be off-set by productivity gains:

Housing is a context far more varied and complex than the climate controlled office or factory. It is also far more varied and complex than the climate chamber, in that such influences as social and economic factors are involved in a different way ... in the home there is an opportunity cost associated with expenditures in pursuit of comfort (Riordan 1992, p.12).

Riordan argues for the vital importance of appreciating context relevance in matters of thermal comfort, and this appears to have more merit than the reductionist method based on observations in controlled artificial situations, as it allows for a less

prescriptive approach when considering appropriate room temperatures for comfort and health. Humphreys' emphasis on the importance of mean external temperature, confirmed in later studies (Riordan 1992, p.38, Auliciems and Szokolay 1997, p.59), also shows the need to allow for seasonal variation in building conditions, rather than striving to maintain a fixed 'neutral temperature'.

Maintenance of neutral temperature conditions also reduces people's ability to adapt to different conditions, or acclimatize, with attendant potential health risks. Folk (1981, p.158) defines acclimatization as 'the functional compensation or physiological adjustment, over a period of days or weeks, in response to changes of environmental factors.' Folk has documented physiological changes in residents of Arizona, USA and in India with the onset of annual extreme summer heat, and refers to other studies which record physiological change and gradually reduced clothing requirement after prolonged exposure to cold (p.159). Adjustments to clothing levels worn in homes in cooler seasons can increase the flexibility in indoor temperatures required for thermal comfort. It is also necessary to be mindful of the important role of radiant temperature in thermal comfort, and how simple measures such as closing curtains at night reduce radiant heat loss (as detailed in section 3.2.1).

3.4 Energy Requirements for Thermal Comfort

Thermal comfort is achieved at considerable expense, possibly consuming a quarter of all energy supplies globally at the end of the twentieth century (Auliciems and Szokolay, 1997, p.62). Additionally, generation of much of this energy by the burning of fossil fuels with the production of greenhouse gases may contribute to atmospheric pollution and global warming (Healey 2000). These factors add to the personal economic need to minimize energy consumption in the pursuit of thermal comfort within the home. In Tasmania, however, there are some overarching climatic conditions which must be taken into account.

Kalma and Auliciems (1980) produced national maps of human thermal stress for Australia for July and January, based on climate. The highest cold stress values in Australia in July were calculated for the Central Highlands of Tasmania, with values for the midlands and southern Tasmania (including Hobart) only rivalled by higher altitude parts of eastern Victoria, Southern New South Wales and Australian Capital

Territory (p.287). The authors also note that in 1927 the American Gas Association observed a direct correlation between domestic gas consumption and the difference between mean outdoor air temperature and a base temperature of 65°F (18.3°C) (p.289). The central importance of external air temperature in relation to heating was confirmed by Durrer and Somerton (1976) in their investigation into determinants of space heating, with humidity and wind velocity assessed as being of secondary importance.

An Australian study by the Institute of Engineers Working Party showed a linear relation between per capita primary energy use for domestic space heating and the annual total of heating degree-hours to a base of 18.3°C for eight Australian capital cities (Auliciems and Kalma 1981, p.18). (The annual total of heating degree-hours was calculated by summing the number of degrees by which the base temperature exceeds the average external hourly temperature for all the hours of a year at a given location). Kalma and Auliciems calculated degree-hours for just the waking hours from 0600 to 2200 Local Standard Time from May to October inclusive to construct a heating degree-hours map for Australia. It showed Tasmania's annual per capita energy needs for space heating are greatest in the Central Highlands and decrease concentrically moving out from that area, with lowest values on the north and east coasts (Kalma and Auliciems 1980, p.291). The values for the Hobart area were the third and fourth highest, and are only exceeded on the mainland in the above-mentioned high altitude areas. Coulson and Thompson (1981, p.16) report that Hobart's heating requirement is among the highest in Australia and that it is not confined to a specific cold winter period.

In 1996 208,000 people lived within 50 kilometres of Hobart GPO (ABS 1996). This represents over 45% of Tasmania's population. These residents have high energy requirements for space heating, and 89,000 of them (almost 20% of Tasmanians) live in municipalities with personal median incomes at that time of less than \$255 per week, lower than the state median of \$257, and substantially lower than the national median of \$292. These figures indicate that a substantial proportion of Tasmanians may have difficulty affording the energy expenditure to achieve thermal comfort in their homes.

There are recommended standards for thermal conditions in housing. The American National Standards Institute (ANSI) and the American Society of Heating, Refrigeration and Air-Conditioning Engineers (ASHRAE) published ANSI/ASHRAE Standard 55-1981, 'Thermal Environmental Conditions for Human Occupancy' in 1981. Soon after, the International Organisation for Standardisation (ISO) published International Standard 7730, 'Moderate Thermal Environments — Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort' (ISO 1984). The ISO standard is based on the climate chamber research of Fanger. Riordan (1992, p.12) refers to two Australian field studies on thermal comfort and preferences in housing which found that the ISO PMV method seemed to consistently over-estimate warm discomfort. Data collected in another field study were analysed by Riordan (1992) to compare recorded thermal sensation and thermal sensation predicted by the ISO 7730 standard and found that the ISO 7730 standard consistently over-estimated warm discomfort in tropical climates and over-estimated cool discomfort in temperate climates. The implication is that Fanger's equation and ISO 7730 standard encourage unnecessary cooling in summer and heating in winter.

Australian Standard 2627 (AS2627, Part 1, 1983, 'Thermal Insulation of Dwellings — Design Guide, Thermal Insulation of Roof/Ceiling in Dwellings which Require Heating') describes a standard method for calculating economic insulation levels. Riordan (1992, p.47) observes that the method is based on locality heating numbers and an assumption that the heated parts of homes maintain 24 hour mean temperatures of 18°C. However, his analysis suggests that maintenance of 18°C for thermal comfort may not be valid. Furthermore, it may be better to determine economic insulation levels using a variable base temperature related to the mean external temperature in the heating season for each locality. His suggestion accords well with the aforementioned observations of Humphreys (1992) (in 3.3), and may avoid problems with unnecessarily high requirements for insulation in the event that such measures become mandatory. Building codes have been upgraded (Victorian five-star and Tasmanian four-star energy efficiency requirements for new dwellings from January 1, 2003) and may in the future encompass extensions and retrofits to existing ones.

In their 'Investigation of the appropriate use of thermal insulation in Tasmania' Coulson and Thompson note (1981, p.19) that a comparison of heating degree days reveals that Hobart's heating requirements more closely resemble those of London and New York than any Australian capital city apart from Canberra. They observe that, as the design, methods and standards of building in Tasmania are based on those for other parts of Australia, Tasmanian housing is not well suited to the Tasmanian climate, and the energy requirements for thermal comfort are likely to impose a significant burden on many Tasmanians, especially disadvantaged groups. Tasmanian standards for insulation should be higher than for most of mainland Australia, yet the State Government has opted for lower mandatory standards on new housing than those introduced in Victoria.

Energy requirements for thermal comfort will depend upon the level of indoor temperature chosen as comfortable, local climate conditions and the energy efficiency of the building. Due to the cool climate, Tasmanian homes need to be more energy efficient than mainland ones to reduce the energy burden on their occupants, although there is evidence to suggest that they are not adequately constructed and insulated. There are higher numbers of financially disadvantaged people in Tasmania than on the mainland and many live in housing which has even poorer energy efficiency than the rest of the state (itself below the national average), so it is more difficult for them to maintain conditions of reasonable thermal comfort.

3.5 Summary

An understanding of the principles of heat transfer can inform design of building elements such as windows, walls and ceilings, as well as the selection of insulation materials and the colour of interior surfaces. The principles can also be an aid to encouraging forms of behaviour within the home to maximize heat gain and minimize heat loss – closing doors to heated spaces, or adjusting window coverings. Thermal comfort has largely been the domain of engineers, but important field studies by other researchers in the field have shifted the emphasis from an approach which seeks to determine a technocratic, one size-fits-all solution to an acceptance of the subjective nature of comfort. At the same time the subjective approach allows for seasonal variation in comfort standards as well as multiple ways of achieving them, including changing clothing levels. Field study work has also recognized the

importance of mean radiant temperature as a measure of thermal comfort, rather than reliance upon air temperature. Technocratic approaches have possibly set indoor temperature targets too high, which wastes energy. On the other hand a more rigorous technical approach would have seen better designed, more energy efficient housing constructed in Tasmania, where the climate requires it. Thus Tasmanian residents, the most financially disadvantaged in Australia, have unnecessarily high energy bills added to their burden. Finding ways to reduce the amount of heat transfer out of existing houses provides the opportunity to increase thermal comfort, mitigate health risks discussed in section 2.3 and reduce financial burden. Methods to retrofit homes for such gains are investigated in Chapter 4.

It was only in 1982, when I took a year's leave of absence from my employment, and lived through a winter in the cottage, that I discovered its major shortcomings. Newspapers carried pictures of children standing on frozen horse troughs just a couple of kilometres away when it was -10°C overnight. At 600 metres altitude, Uraidla could also spend several consecutive days fog-bound. As I was surviving on casual work, the trained frugality came to the fore in seeking ways around the problem of a house too cold for comfort. It was that winter when I began trying to direct any warmth in the sunroom up the split-level to the dining room, or, on cloudy days, closing all doors and running the old slow-combustion stove in the kitchen to heat just that room and the adjacent dining room. By now the requisite books were available, having been published in response to the first oil crisis, so I consulted some I had bought in that time. A new batch was just becoming available following the recent second crisis of 1979-80 and I purchased a few more as I began important lifestyle-improving research.



Many of the books were published in America, and I recalled some of the techniques of a friend whose house I stayed in near the border of Minnesota and North Dakota. Daily temperatures had ranged from -15°C to -20°C , but at night he insulated the large glazed areas of his passive solar house most effectively with lightweight styrofoam panels he had made up. Another friend in Maine in a passive solar house had so much heat to feed up to the upstairs bedrooms that it was necessary to close the bedroom doors at night to be cool enough to sleep; this, despite it being -40° one morning while I was there. Coping with overnight lows of -2°C and a rare -10°C I figured would not be particularly daunting.

CHAPTER 4: RETROFITTING TECHNIQUES

4.1 Introduction

Application of the heat transfer principles from section 3.2 to the building envelope forms the practical basis for retrofitting a home to make it operate in a more energy efficient way. Adapting a definition from Spielvogel (1982, p.269) for non-residential buildings, the *building envelope* can be defined as all the elements of a dwelling that enclose the living spaces, through which thermal energy may be transferred to or from the living spaces. These elements include the roof, walls and floor and parts of them such as doors and windows.

The four main techniques for modifying heat transfer through the building envelope will be discussed in increasing order of their complexity and expense, commencing with infiltration and insulation before addressing the more difficult procedures of altering the solar inputs and thermal mass of a structure.

4.2 Reducing Infiltration

Infiltration is the uncontrolled leakage of air through cracks in any building element and around windows and doors, caused by the pressure effects of wind or the effects of differences in indoor and outdoor air density (Spielvogel 1982, p.269). It is necessary to distinguish between infiltration and ventilation, the latter being necessary and controllable, as will be discussed at the end of this section. Usually air leakage is into the building and is of concern because it brings cool air into a heated space, but it may also be outward through the building envelope and removing warm air from a heated space. It has been estimated that this free air movement can account for up to 35 percent of the total heating load in a properly insulated but 'leaky' house (Vandervort 1978, p.51). When infiltration is due to pressure effects of wind, the rate of air movement depends on wind speed, wind direction and direct exposure of the house to wind (Pitts and Willoughby 1992, p.202). To some extent wind impact can be mitigated by suitably placed, well-designed windbreak plantings (Olgyay 1963, Coldicutt *et al.* 1978).

Even in a well-sheltered house some external air movement will inevitably reach the building envelope and must be dealt with at that point. The material used to reduce infiltration is called weatherstripping. Some forms of weatherstripping will also repel wind-driven moisture and rain. The material is relatively inexpensive and installation is quite simple, yet resultant fuel savings are potentially quite substantial.

Major sources of air infiltration are gaps around external doors and windows. For example, loose-fitting, single-glazed windows usually lose more heat than they admit in the form of solar heat gain (Total Environment Action Inc. 1984, p.22). Even a door which fitted well when installed in a new house, will have had a gap beneath it to enable it to swing clear of the floor. This gap can be blocked by fitting a timber or metal strip called a threshold to the floor beneath the door when it is in a closed position, and attaching a flexible strip called a door sweep to the bottom edge of the door so that it sits lightly on the threshold. The door sweep is fitted to the side of the door towards which it opens (Vandervort 1978, p.65). As a door ages it may also begin to fit poorly on its other edges against its jambs. The weatherstripping used to seal around door jambs is usually adhesive-backed compressible foam plastic, which can also be used for sealing hopper windows hinged at their top. The same material is available in different profiles for other applications, such as the double-hung sash windows common in many older Tasmanian homes, for which it is inserted into the channels in which the sashes slide. A felt strip can be used to seal the surfaces along which the two sashes meet when both are closed. The inexpensive rolls of weatherstripping come with simple instructions for installation, making the closing of infiltration gaps around doors and windows a simple task for residents and an easy way for them to reduce heat losses.

Other sources of infiltration that are simple and inexpensive to eliminate are gaps in the external walls themselves. Aging weatherboards can develop splits, and both timber and brick walls may have poorly fitting service installations (pipes and cables) passing through them. All can be sealed readily with silicone caulking compounds, which can also be used for the gaps around window frames that fit poorly into walls.

One quite substantial source of infiltration is chimneys, often unused, which can have wind gusts and draughts blow down them. There is also potential for the effect

of winds blowing across their open tops reducing air pressure at the top of the chimney and thus drawing air up out of the house through the chimney. If unused they can be permanently sealed at the top with a metal plate and flashing, or if occasionally or seasonally used it may be more appropriate to insert a removable cover across the bottom of the chimney.

After sealing obvious gaps in the external building envelope by such means, further reductions in infiltration may prove difficult, as illustrated by the range of possible paths in Figure 4.1. Pitts and Willoughby (1992, p.203) describe how an attempt at tracing leaks in 15 masonry houses found that 67 percent of leakage was through unidentifiable paths. They suggest that a key part of an effective strategy is to treat the inner skin of the building envelope as an air barrier which must have its integrity retained. It is necessary to ensure that all service penetrations through the inner skin are well sealed with silicone, and that the walls are sealed to the outside of the window frames (as was described for the external skin), to prevent air leakage into the wall cavity of timber-framed houses, for example.

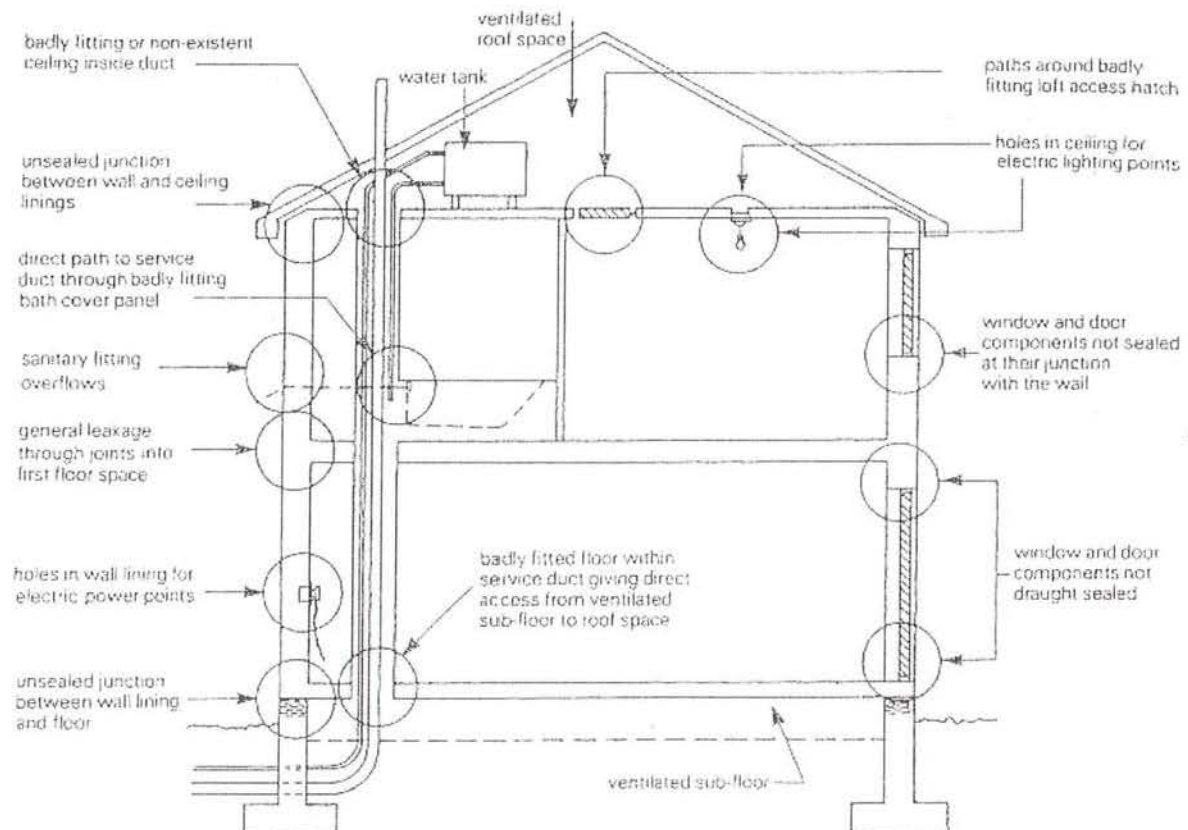


Figure 4.1: Typical air leakage points

Source: Pitts and Willoughby (1992, p.202)

Another contributor to infiltration is when stratification of room air occurs (see 3.2.3) and warm air leaks out of cracks and gaps around the top of walls or in ceilings. Stratification may be quite significant in a multi-storey dwelling with an open staircase. Thus the effectiveness of seals around ceiling mouldings is of great importance. Additional sources of leakage are penetrations in ceilings for downlights, gaps between walls and floors, gaps between floorboards (old boards can have significant shrinkage) and powerpoints in external walls.

While the main focus in reducing infiltration is the building envelope, if a dwelling is being thermally zoned rather than heated throughout, it can be useful to seek to reduce infiltration internally within the house by sealing air gaps around the heated space. If the doors are weatherstripped and door sweeps are put across their bottoms, it is possible to reduce the draughts which lead to reduced thermal comfort within the heated space, that may result in occupants feeling the need to raise the level of heating.

Many older houses have fixed vents set in their walls and, provided they are not needed to control dampness, they should be sealed off as they are no longer required by the building code. Research has found that such houses with vents in each room and exposed timber floors can have 10 to 15 air changes per hour compared with modern homes on concrete slabs which commonly have approximately two air changes per hour (Ballinger, Prasad & Rudder 1997, p.95). When a dwelling has been sealed against infiltration, paradoxically it is also necessary to ensure that it has good ventilation for the comfort and safety of its occupants, and for condensation control (Vandervort 1978, p.22). Beyond the use of natural ventilation in most living rooms and bedrooms, it is necessary to provide for much higher ventilation rates in the kitchen, bathroom and laundry where high moisture levels are frequently created. The extraction fan in a kitchen is best located in an external wall directly above the stove, whereas in a bathroom or laundry anywhere in the external wall is satisfactory, due to the generally high moisture levels throughout the room (Pitts and Willoughby 1992, p.204). The extraction fan needs to be self-sealing when not in use, lest it be a major source of infiltration. However, in extracting moist air, exhaust fans also extract heated air. An air-to-air heat exchanger uses stale moist air to pre-warm incoming cold air.

4.3 Improving Insulation

The majority of heat loss from a dwelling is by conduction of heat through walls, ceilings and floor. The thermal resistance (R-value – see 3.2.2) of conventional structural materials is not sufficiently high to prevent this direct heat transfer. It is variously estimated that from 27-70 percent of the heat loss of a house is through its roof, 16-40 percent through the walls and floors, and up to 19 percent through doors and windows (Vandervort 1978, Ballinger, Prasad & Rudder 1997). The four star design regulations for new homes in Tasmania specify that added roof insulation should be a minimum of R3.0 and wall insulation a minimum of R1.0 in climate zone 7, which applies to all new homes below 900 metres elevation (HIA 2002). As there have been no mandatory requirements for housing in Tasmania to have insulation fitted at the time of construction until January 1st 2003, many residences in the State could benefit from retrofitting of insulation.

4.3.1 Insulation Materials

Insulation materials are generally classified as bulk materials, rigid lightweight boards or reflective foil laminate (RFL) (Vandervort 1978, Ballinger, Prasad & Rudder 1997). Bulk materials (glass fibre batts and loosefill insulation) rely on the thermal resistance of trapped air as described in 3.2.2, as do the rigid lightweight boards of compressed fibreglass, polystyrene or polyurethane which have gas trapped in cells formed during the plastic foaming process. Loose-fill insulation (shredded paper/cellulose fibre) settles after installation reducing its effectiveness in ceilings, and leading to it not being used in walls at all. RFL works by reflecting radiant energy and also acts as a vapour barrier (see 3.2.2), and is usually used in conjunction with one of the other two types of insulation. The importance of RFL being installed with overlapping sections, preferably taped together and with no tears or holes has often been stressed (Vandervort 1978, Ballinger, Prasad & Rudder 1997), as has the need to ensure that there are no gaps in other forms of insulation, and that it is not compressed during installation.

There is another type of insulation which is rarely used in Australia and about which there have been some health concerns – urea-formaldehyde foam, which can be pumped into wall cavities as a liquid where it sets. The concern is with the formaldehyde vapour released as it sets, which has led to it being banned in some countries (Warren, Kember & Haas 1983, p.12). These health concerns are sufficient to preclude its use for insulation retrofits.

4.3.2 Walls

Heavy materials such as concrete and bricks are sometimes referred to as capacitive insulation. They slow the passage of heat and this property of thermal inertia can be used in conjunction with resistance and reflective insulations. Greenland and Szokolay (1985, p.30) present the concept of an ‘ideal wall’ which they suggest should be heavy and have external insulation with a lightweight waterproof skin on the outside. Such a form of construction is rare in Australia, and the most common compromise is the aforementioned double-brick cavity wall construction, although reverse brick-veneer would be the closest approximation, and has other advantages (see 4.5 Adding Thermal Mass). Retrofitting a brick wall to the inside of a timber-framed wall, with insulation added between the two, could be done readily if there was a slab floor, but is an expensive option for improving insulation – even though the gain in thermal mass would further increase efficiency. It is possible, but even more expensive, to retrofit brick walls inside a timber-framed and –floored house by first removing the floor and pouring a suspended slab on steel-reinforced decking supported by the existing footings (Reardon *et al.* 2004). It is recognized (Ballinger, Prasad & Rudder 1997, p.140) that in general wall insulation is difficult to retrofit due to restricted access. Timber-framed walls are not necessarily any easier to retrofit than brick ones, although with both types it is possible to fix a batten framework to the inside of the wall, put insulation within the framework and cover it with a new wall lining – again not inexpensive. However for the estimated 14 per cent savings in heating costs (p. 138), this option may be cost-effective in the medium-term. (The same method can be used for a ceiling under a flat roof.)

4.3.3 Ceilings

Insulating a ceiling is considered the second most cost-effective retrofitting method after reducing infiltration losses (Jensen 1988), and can reduce heating needs by 25 per cent. If the ceiling space is large, installation is quite simple, although the insulation batts are relatively expensive – a problem which may be circumvented by using a cheaper alternative material (see 4.3.7). Insulation batts must be placed next to each other with no gaps. Ceiling insulation serves a dual purpose as it also reduces heat entering the house in summer.

4.3.4 Floors

Timber floors can lose considerable heat if they are raised and the sub-floor space is open to free air movement. While some underfloor circulation is necessary to avoid dampness problems, too much should be avoided. If it is not possible to reduce the airflow, installation of at least R1.0 batts between the floor joists is required in the energy efficiency regulation changes to the Building Code of Australia effective from 1st January 2003 in Tasmania (HIA 2002). The stapling of heavy-duty reflective foil laminate across the bottom of the joists will reduce radiant heat transfer and seal in a stationary air gap, as well as excluding rodents from the batts.

4.3.5 Windows

After sunset there is heat loss through windows by radiation and by conduction through the glass. The thermal resistance of 4mm window glass can be increased from R0.17 to R3.0 by the use of close-fitting heavy drapes with a pelmet, as described in 3.2.3 (Ballinger, Prasad & Rudder 1997, p.81). Heavy drapes can be quite expensive even to make, if a resident has the skills, but many houses already have drapes which may only need the addition of lining material. Some houses have heavy drapes and only need a pelmet of simple construction above them.

Double-glazing is commonly used in very cold climates to create a trapped air space between the panes of glass and thereby increase thermal resistance. It is expensive to fit in new homes, and both expensive and often difficult to retrofit in existing ones. The time for double-glazing to repay its expense in reduced heating bills is

considerable, but an inexpensive option is the purchase of plastic sheeting which can be attached by velcro strips to the inside of the window frame as a temporary, or seasonal, measure.

4.3.6 Hot Water System

Hot water systems may consume an average of 27 per cent of the energy used in an Australian house (Harrington & Foster 1999b, p.4)) and are the largest source of residential greenhouse gas emissions, accounting for 30 per cent of the domestic total (AGO 1998). Energy use for hot water heating is of the same order as for space heating in moderately insulated homes and can be substantially more than for space heating in well-insulated homes (Pitts and Willoughby 1992, 214). Heat energy stored in a hot water system is lost continuously through the walls and top of the tank to the surrounding air, with some sources (AGO 1998) considering that total hot water heating losses are in the range 30 to 50 per cent and may be as high as 60 per cent. Losses would be higher for the large number of tanks located outside Tasmanian homes where the air temperature is substantially lower than in all other capitals except Canberra. From Table 4.1 it can be seen that, of all the capital cities in Australia, Hobart has the lowest average air temperature as well as residential cold water temperature, so more energy is required to raise the water temperature in hot water systems.

Table 4.1: Average air and water temperatures for Australian capital cities

City	Average annual air temperature (°C)	Average residential cold water temperature (°C)
Sydney	18.2	18.3
Melbourne	15.5	16.2
Brisbane	20.6	21.0
Adelaide	16.4	17.9
Perth	18.4	20.7
Hobart	12.9	12.9
Canberra	13.1	15.0

Source: Harrington and Foster (1999a)

There are further heat losses from mains pressure-relief valves which dump two to five per cent of the volume of heated water, as well as conducting heat away through the valve and the overflow pipe (AGO 1998). The hot water delivery pipe is copper, an excellent conductor, and heat losses can be substantial for long runs to wet areas, especially if the tank is located outside.

These losses can be greatly reduced by wrapping insulation batts around the walls and over the top of the tank and securing them with duct tape, leaving the pressure relief valve, thermostat and cabling open for access. This task is easily accomplished by most people at very low cost. For hot water systems located outside the building it is necessary to construct a weatherproof boxing around them before installing the insulation, and this adds to the expense, although the reduction in energy consumption makes this a cost-effective measure to take. In addition the hot-water pipe from the tank should be covered with weatherproof lagging wherever it is exposed, or in the case of an indoor tank, for the first metre from the tank (Crossley 1980, p.21, AGO 1998). Heat losses from hot water systems are so substantial that they should be regarded as the worst form of stand-by energy loss in a house.

4.3.7 Alternative Insulation Materials

The major barrier to the insulation of homes may be the cost of the materials. A survey of Australian social trends on household energy use found that the largest proportion of people (33 per cent) gave cost as their reason for not insulating (ABS 1998). Apart from the conventional manufactured insulation products there are other materials available with good insulating qualities, which, if they were sufficiently inexpensive, could make the task more affordable. In the USA vermiculite and perlite have been used as loosefill insulation in ceilings (Croy and Dougherty 1984, p.56, Vanderwort 1978, p.33). Both products are widely used in the horticultural industry in Australia to improve drainage in potting mixes. Shredded paper (also known as cellulose fibre) is quite widely used in the USA and was commonly employed for ceiling insulation in Tasmanian public housing (Coldicutt *et al.* 1978, p.5). Made from recycled newspapers, it has good environmental credentials, and has been used to insulate an energy self-sufficient house in the UK, where it was filled to a depth of half a metre above the ceiling (Vale & Vale 1993). The shredded paper is treated with boracic acid or borax to render it resistant to fire, moisture, fungal

growth and rodents, but if the treatment is at the wrong concentration it can result in corrosion to metal in the ceiling space (Croy and Dougherty 1984, p.48). If a reliable method for the borax treatment could be devised for the home handyperson/Do-It-Yourself person, people could be empowered to produce and install their own insulation.

Health, safety and insurance issues become significant in building alterations, and the emergence of new techniques and materials can be impeded. In a submission to the Productivity Commission Inquiry into Energy Efficiency, the Business Products Innovations Council raised issues to do with the time taken to get innovative products to market (McDonald 2004, p.3). New materials cannot be used until either the Australian Standards or the Building Code of Australia (BCA) is amended, so that the product complies with the BCA and the insurance issues are covered. Amendments and state and national regulatory changes cause significant delays and stifle innovation and research. A suggestion made is that encouragement could take the form of 'increased incentives for developments in specific areas, for example lightweight insulation or other energy efficiency initiatives' (p.3). The situation remains that commercial interests and government bureaucracies determine both the type and rate of change in availability of materials and energy efficient techniques.

4.4 Increasing Solar Input

Solar input is here defined as the amount of energy that is able to enter a structure as a result of direct solar gain (solar radiation), and/or natural convection of solar heated air. In section 3.2.3 a distinction was drawn between active and passive solar systems. Active systems require inputs of conventional energy to power mechanical means of distributing the air which has been heated by solar radiation. They are considerably more expensive than passive systems and beyond the scope of this study, as detailed below. Thus only the principles of passive solar design for housing will be considered, and even then with some restrictions.

Passive solar design involves the construction or modification of a building so that it is able to admit solar energy, store it and distribute it by natural means with minimal losses (Clarke 1979, Parnell & Cole 1983). Solar gain can be maximized by three techniques (Pitts and Willoughby 1992, p.209):

- The house should be oriented with its long axis east-west and its living spaces facing north;
- The glazing should be concentrated on the north wall; and
- Windows are not to be obscured by blinds or curtains during the day

With an existing dwelling, options for increasing solar gain by retrofitting are rather limited. Orientation can only be improved if extensions are planned and it is possible to make them in such a way as to increase the length of the east-west axis of the house. (It is worth mentioning that it has been found that surfaces oriented up to 30° east or west of north receive almost as much solar radiation as ones facing true north (Total Environment Action, Inc. 1984 p.20)). Occasionally it may be possible to rearrange room use at the same time so that living spaces are on the north side. Increasing the glazing on the north wall also requires significant structural intervention which may be quite expensive.

A key aspect of this thesis is the investigation of retrofitting techniques that are inexpensive and, where possible, within the capabilities of a significant proportion of the population. In view of the focus, this section will briefly summarize each method for increasing solar input, focusing on those best satisfying such criteria. In their comprehensive approach to passive solar design, Total Environment Action Incorporated (TEA) published a set of passive solar design concepts in conjunction with detailed design analysis and design performance data from the Los Alamos Scientific and National Laboratories in 1984. They grouped passive solar energy systems according to five physically identifiable methods of operation:

1. Direct-Gain Systems
2. Thermosyphoning Systems
3. Attached Sunspaces
4. Thermal Storage Walls
5. Thermal Storage Roofs

As thermal storage roofs can only be supported by a purpose-built stalwart construction, they will not be discussed here. Thermal storage walls will be discussed in section 4.5 Adding to Thermal Mass.

4.4.1 Direct-Gain Systems

Direct gain systems have been described as the use of a relatively large proportion of glazing on the north wall to allow low-angled winter sun to penetrate deeply into the house to directly heat the interior (Clarke 1979, Parnell & Cole 1983, Greenland & Szokolay 1985). The Building Code of Australia requires that for homes in climate zone 7 (all of Tasmania below 900 metres altitude) glazing in the north wall range from 25 to 33 per cent of total floor area, depending on the type of glass and frame used (HIA 2002). If heavy masonry is located in the floor and walls where the sun can shine on it, excess solar heat can be stored. Baker (1981, p.122) recommends at least 700kg of masonry material for each square metre of north-facing glazing. Heavy curtains on the windows insulate the glazing from night heat loss, but must be open during the day. For summer, the roof eaves need to have sufficient overhang to prevent the sun from shining through the glazing (Figure 4.2).

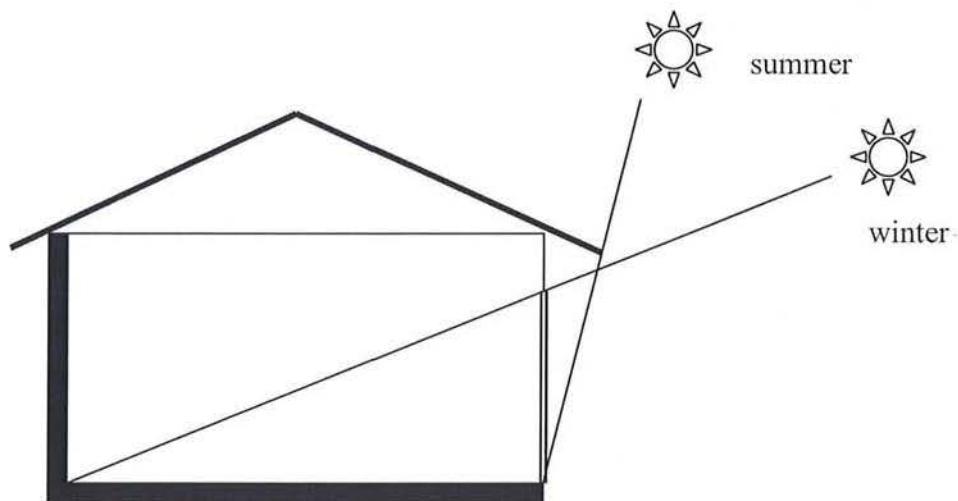


Figure 4.2: Direct gain system

4.4.2 Thermosyphoning Systems

Figure 4.3 illustrates a simple thermosyphoning air collector. It consists of a 75 to 150mm air space between a pane of glass and a wall which is both light-weight and has been painted black so that it heats up very quickly, and is insulated on the back (Parnell & Cole 1983, p.22). The air in the space is heated and rises by convection to pass out the top vent into the room behind. Cool air at floor level in the room flows

into the collector through the bottom vent and a convective loop is established which functions only as long as the sun shines on the collector. Convective airflow is created by the difference in temperature on both sides of the loop, and is also affected by the height of the loop (the greater the height, the greater the airflow). The vents need to be closed at night to prevent reverse cycling which would feed chilled air into the room through the bottom vent. TEA suggest (1984, p.32) that the vents be about five per cent of the collector area, and that in conventional wood-framed residential constructions up to 25 per cent of the heating load can be supplied by such a collector, although it would be best to not rely on an amount in excess of 10 per cent.

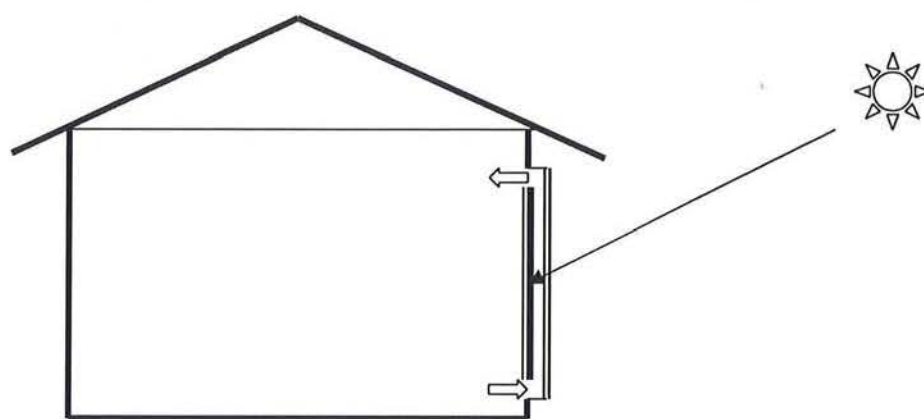


Figure 4.3: Thermosyphoning system

For a house with a north facing wall the retrofitting of such a collector would be cheaper than fitting a window for a direct gain system. The requirements are black paint, timber boxing and well-sealed glazing on the outside of the wall, and the provision of vents in the wall and insulation behind it if there is none. It is not a major retrofit, and, although glass is expensive, has the capacity to reduce heating expenses markedly – especially for people who are home regularly during the day. If the glass were recycled from a secondhand window and the installation done by a home handyman, the retrofit becomes quite inexpensive.

4.4.3 Attached Sunspaces

A sunspace is a 'lean-to' type of structure similar to a greenhouse preferably built on to the north wall of a house, or at worst the north-west corner. It may have all walls

and the roof covered in glass or corrugated fibreglass or plastic, or only the north wall and roof. The dividing wall between the sunspace and the house may be of solid masonry to store heat which is shared by both the sunspace and the room behind it, or a window wall which can be opened to admit the heated air into the house. An attached sunspace has the added advantage, especially if it has a masonry wall, of extending the growing season for plants in cool climates (Clarke 1979, TEA 1984), as well as providing an additional living space for part of the year (Vale & Vale 2000). In addition to providing heat for the house, the sunspace also acts as a buffer to reduce heat loss in windy conditions and at night.

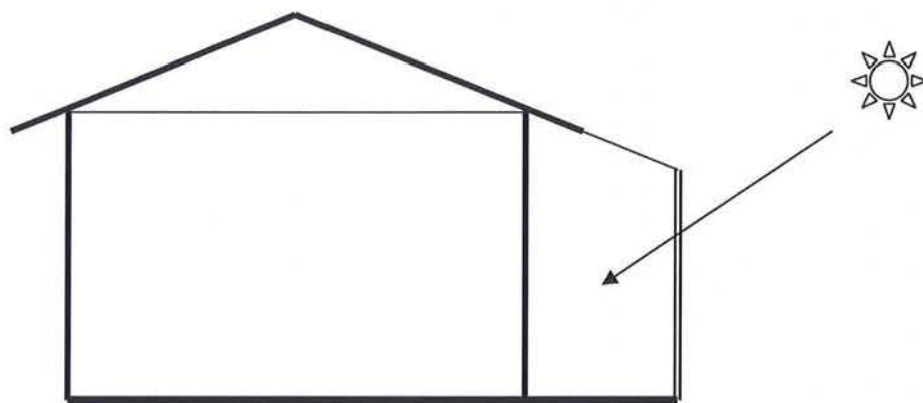


Figure 4.4: Attached sunspace

The construction of an entirely new sunspace would be quite an expensive exercise although if recycled windows were used this could be reduced significantly. However, many older houses have a verandah, sometimes partially enclosed, and if this were on the north or north-west side of the building it could be fully enclosed with recycled windows relatively inexpensively to create a functional sunspace.

4.5 Adding to Thermal Mass

4.5.1 Materials

Thermal mass is the material of a building which absorbs or releases heat from or to the interior space (Baker & Steemers 2000, p.36). The material involved is generally part of the structure or envelope and is relatively dense masonry such as concrete, brick or stone. The property which describes the ability of a material to store heat is

known as its specific heat (Sears and Zemansky 1964, p. 307). The specific heat is the amount of heat energy required to raise the temperature of one kilogram of the material by 1°C, although for buildings it may be more relevant to consider the volumetric specific heat, or heat capacity – the heat required to raise the temperature of 1m³ of the material by 1°C (Baker & Steemers 2000). Table 4.2 shows specific heat and heat capacity values for some common building materials.

Table 4.2: Typical values for heat capacity of building materials

Material	Specific Heat (kJ/kg°C)	Heat Capacity (kJ/m ³ °C)
Expanded polystyrene	1.00	25
Fibreboard	1.00	300
Softwood	1.20	730
Hardwood	1.23	900
Lightweight concrete	1.00	1000
Gypsum plaster	1.10	1050
Brick	0.80	1360
Dense concrete	0.84	1760
Water	4.20	4200

Source: Baker and Steemers (2000, p.36)

The advantages of thermal mass in a structure are increased by what Baker and Steemers (2000) call the degree of coupling which the thermal mass makes with the interior space (2000, p.36), which refers to both the distribution of the thermal mass and its direct contact with the air space. Thermal mass is most effective if evenly distributed about the space, and if it is not separated from it by any other material such as a light-weight wall surfacing or a floor covering as is commonly the case (Baker & Steemers 2000, p.37). In addition, the major thermal mass of a house is usually its concrete floor, and as Greenland and Szokolay (1985, p.29) note, if that mass is also ground coupled (in direct contact with the earth) it adds an enormous thermal inertia to the house system. Thermal inertia acts to reduce the diurnal temperature swing from solar gains during the day and heat losses at night, as well as delaying the time of temperature peaks. Such a time lag results in the provision of re-radiated heat after sunset, reducing space heating needs. Ground coupling can lead to

heat loss if the slab is on damp earth, although the Building Code of Australia only specifies edge insulation around the heated part of the slab for climate zone 7.

Furthermore the thermal mass has its greatest effectiveness if it receives direct solar gain as illustrated in the Direct Gain System in Figure 4.2, enabling it to store the most heat during daylight hours for night-time radiation into the living space. Thermal mass that is not exposed to direct solar gain or in a heated space contributes mainly by reducing the diurnal temperature range of the space it is in. If that space is to be heated on an irregular basis, the thermal mass may render that task more difficult.

The final type of passive solar design system in addition to those in section 4.4 is the thermal storage wall system.

4.5.2 Thermal Storage Wall System

Of the two types of thermal storage wall the second has more design elements in common with a thermosyphoning system (Figure 4.5; see also section 4.4). In both, the wall at the rear of the north-facing air space is a massive masonry construction of high thermal inertia, so that it absorbs a large amount of heat during the day for transmission through into the room behind. This transmitted heat is available to the room after a time delay proportional to the thickness of the wall. Cofaigh *et al.* (1996, p. 80) consider the time lag to be 18 minutes per 10 mm wall thickness, and thus a wall 250mm thick would reach its maximum temperature on its internal surface around 8pm. The second form of thermal storage wall has vents top and bottom like a thermosyphoning system and also delivers convective heating during the day. It is known as a Trombe-Michel Wall (or Trombe Wall) after the developers of its design.

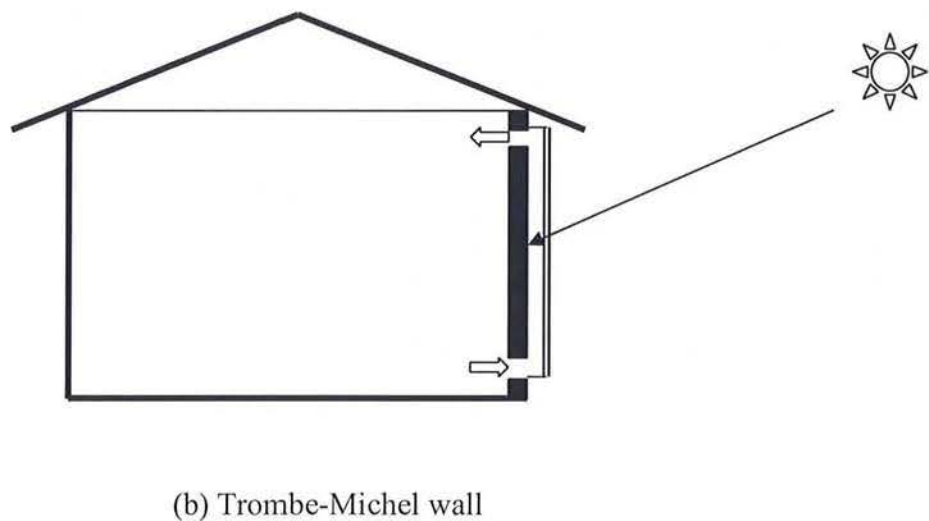
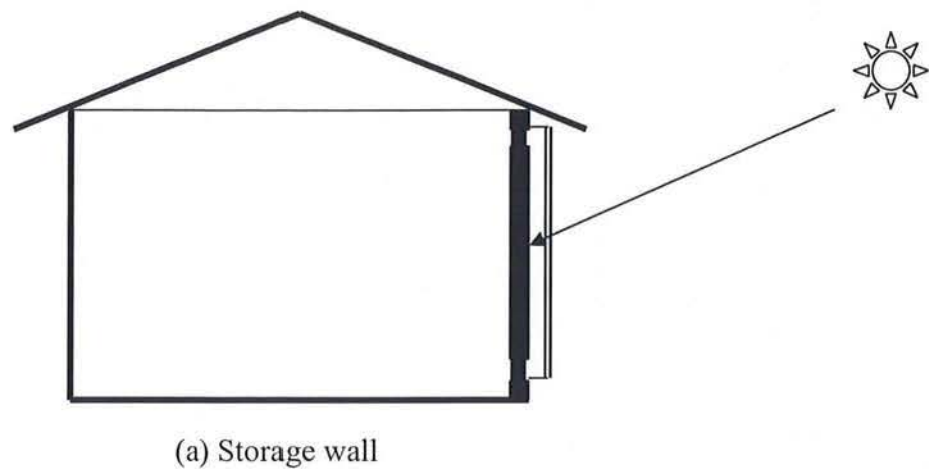


Figure 4.5 Thermal storage walls

As the installation of concrete slabs and heavy masonry walls is expensive and a major assault on the structure of an existing house, from the point of view of inexpensive retrofitting it is necessary to work with existing masonry. If a house has an existing slab floor, it is necessary to maximize its coupling with the interior space by removing any soft floor coverings, especially where direct sun strikes it in winter. Furniture shading that part of the floor could be moved, at least during the day. A common building type in Australia is double-brick cavity wall, which led a West Australian to develop a variation on the Trombe-Michel wall – the Lawrance wall (Parnell & Cole 1985, p.21). Glazing is fixed to the outer brickwork which has been painted black, but vents are only incorporated in the inner leaf of brickwork (Figure

4.6). The wall cavity is sealed on all sides. The convective loop establishes in the wall cavity later in the day, after heat has passed through the outer layer of bricks, and continues after sunset. Radiant heat from the wall is emitted after the appropriate time lag. The Lawrance wall has the advantage that any leaks in the glazed air space do not affect the ability of a convection loop to establish, and they do not affect the integrity of the building envelope. Retrofitting is relatively inexpensive.

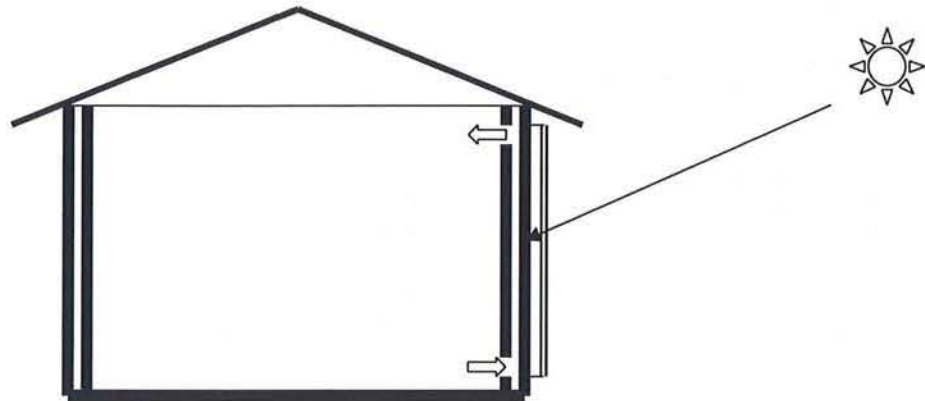


Figure 4.6: Lawrance Wall

An inexpensive way to introduce thermal storage mass into a house through the addition of a lightweight attached sunspace like that in Figure 4.4 is the addition of black-painted 200 litre drums filled with water (Clegg & Watkins 1980, p.186). Water has the highest specific heat of all substances (see Table 4.2) and re-radiates at night the heat it has absorbed during the day, moderating the temperature in the sunspace. If insulation can be drawn across the sunspace glazing at night, such as curtains around the windows of a glazed-in verandah, the re-radiated heat is also available to the adjacent room.

4.6 Summary

In seeking to improve the energy efficiency of a dwelling, no matter what overall strategy is decided upon, sealing the building envelope at the inner surface is an essential first step. Achieving this first step may test the budget and capabilities of the most disadvantaged groups. Improving insulation levels in the ceiling to at least the BCA requirements for new homes in the local climate zone is the most cost-effective second step, but may be too expensive for a significant number of people, and currently is out of the control of people who are renting. The retrofitting

techniques for improving solar gain range from relatively simple, inexpensive measures for a house which already has good orientation and north wall glazing (where removing bushes to decrease shading may be sufficient), through thermosyphoning systems to conversion of a verandah or construction of a new sunspace. As expensiveness is a subjective term, there may be quite a few homeowners who consider one of these measures worthwhile, especially if they were already contemplating renovations. The techniques for increasing thermal mass are sufficiently complex, expensive and suited to a limited number of structural types to render them irrelevant to many homeowners.

Unfortunately the most disadvantaged – elderly people paying rent, for example – could find all of these techniques impossible to achieve. Even the draught-proofing requires financial investment in the landlord's house. For homeowners the choices after draught-proofing and ceiling insulation are dictated by availability of finances, personal skill levels and the techniques best suited to their home. Retrofitting can be conducted incrementally, doing the most cost-effective things first, or the ones which add most to the comfort levels and living experience of the home.

Before progressing to a discussion of ways to enable more people to engage in retrofitting activities, Chapter 5 depicts the broader social and environmental context for the retrofitting of houses.

In 1973 an article appeared in New Scientist on the possibility of the earth plunging into an ice age. A decade later no signs of this were evident in South Australia. The heat of summer, even in the elevated Hills area, reached such extremes in the El Nino of 1982 that after ten consecutive days above 37°C, peaking at 45°C, I began to consider an ice age a desirable event. Failing that, at least a cooler climate somewhere. The sunroom in the north-west corner of the house, with internal wall temperatures on the concrete block west wall peaking as high as 40°C at 10pm, proved to be poorly located. (It is entirely possible, in what one finds an extreme climate, to become rather temperature-obsessed.) Even the 25 centimetre thick mudbrick walls and the insulated ceilings were inadequate to the task of keeping the bedroom cool. I came to resemble my heat-stricken Plains colleagues. I couldn't decide whether Adelaide's weather was becoming more extreme, or my tolerance was diminishing. When, in the 1983 Ash Wednesday bushfires, mortality licked at the side fence, and flitted away on a fickle wind change, it seemed like a good idea to get serious about that cooler climate dream.



CHAPTER 5: A MULTISCALAR CONTEXT FOR RETROFITTING HOUSES

5.1 Introduction

In 1983, as conflict grew between economic interests and those concerned about resource depletion and ecosystem degradations, the United Nations appointed a commission to attempt to formulate an approach called 'sustainable development'. In 1987 the commission produced the Brundtland Report *Our Common Future*, which presented the concept of sustainable development: development which meets the needs of the present without compromising the ability of future generations to meet their own needs. Embedded in the principle of sustainable development are two key concepts: firstly, the concept of prioritising the essential needs of the poor by considering both intra- and inter-generational equity; secondly, the idea of the limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs (WCED 1987, p.43). A number of international conferences were subsequently convened, including the 1992 and 2002 Earth Summits and the 1994 International Climate Change Convention. At these conferences attempts were made to gain consensus on a global approach to a wide range of issues for which previously accepted development practices could pose a threat to the ecosystems and the environment, with the potential to seriously compromise future generations. In this chapter I review some of these international debates, assess how they led to new national initiatives, and describe the creation of new structures to promote sustainable approaches to development at state and local government levels, with a particular emphasis on energy and the atmosphere.

5.2 International Council for Local Environmental Initiatives

In 1990 a World Congress for Local Governments for a Sustainable Future was held in New York at the United Nations Headquarters. The congress was held in conjunction with the United Nations Environment Program (UNEP) and the International Union of Local Authorities (IULA) along with representatives from over 200 local communities in 45 countries, 25 national alliances of local authorities and representatives from government and non-government organisations (Lafferty and Eckersberg 1998, p.10). During the congress these groups founded the International Council for Local Environmental Initiatives (ICLEI), which has the

declared mission to build and serve a worldwide movement of local governments to achieve improvements in global sustainability, focusing on environmental conditions, through cumulative actions.

At the 30th World Congress of IULA in 1991 the 'Oslo Declaration on Environment, Health and Lifestyle' was developed on the general outline of the 1987 Brundtland Report. The declaration clarifies the role of local authorities in working for sustainable development at the local level by involving their own residents, and at the global level by forming international alliances between and among municipalities. In the same year, the Secretariat for the United Nations Conference on Environment and Development (UNCED) invited ICLEI to prepare a draft of Chapter 28 of Agenda 21, including a mandate for local authorities to prepare a 'local Agenda 21 (LA21)', for the 1992 Earth Summit (to be expanded upon in Section 5.3).

In 1993, at an international summit of municipal leaders held at United Nations headquarters in New York, ICLEI established the Cities for Climate Protection™ (CCP™) Campaign (described in detail in Section 5.4). ICLEI was one of the principal organisers of the European Conference on Sustainable Cities and Towns which adopted the 'Aalborg Charter', to which over 120 European cities and towns had subscribed by 1998 (Lafferty and Eckerberg 1998, p.11). The Charter provided an important stimulus for some more specific LA21 initiatives. In 1996 at the Second European Sustainable Cities and Towns Conference at Lisbon, municipal representatives endorsed a set of 12 principles, the 'Lisbon Action Plan'.

ICLEI spreads information on these historic benchmarks, publishes its own newsletter, co-ordinates a range of Local Agenda 21 programs and documents best practice examples of local leadership in sustainable development as well as case-studies of local environmental initiatives. The organisation's head office is in Toronto, Canada and a dozen regional offices (including one in Melbourne) are distributed over all continents, enabling it to have an ongoing role in communicating ideas for local sustainable action to a wide range of local government bodies around the globe.

5.3 Local Agenda 21 Action Plan

In 1989 the UN General Assembly passed Resolution 44/228 to determine an approach to sustainable development. Two years of research, drafting and intense negotiations at the four meetings of the UNCED preparatory committee resulted in the adoption at the 1992 Earth Summit in Rio de Janeiro of Agenda 21, an international consensus on actions for sustainable development (Kelly 1992, p.13). Its 40 chapters were intended to encourage governments, industries and communities to engage in actions to reduce human impacts on the environment and lead to the establishment of ecologically sustainable forms of production. After the 1992 Earth Summit Australia formulated a National Strategy for Ecologically Sustainable Development (ESD). Kelly (1992 p.7) alludes to some difficulties in negotiating the chapter on atmosphere due to some fossil-fuel dependent nations claiming there was an over-emphasis on new and renewable energy sources and on problems associated with high levels of energy consumption. Of note is the absence of a chapter on energy.

Agenda 21 consists of four sections:

- Social and Economic Dimensions – examining human factors and problems of conventional development;
- Conservation and Management of Resources for Development – which presents the range of resources and ecosystems and the threats confronting them;
- Strengthening the Role of Major Groups – looking at the social partnerships which will need to be developed at all levels of government down to local communities; and
- Means of Implementation – dealing with the changes to management of human resources and institutions necessary to achieve sustainable outcomes.

As described in Section 5.2, ICLEI formulated Chapter 28 as part of the Major Groups section of Agenda 21, and it was titled Local Authorities Initiatives in Support of Agenda 21. Chapter 28 deals with the vital role of local government in bringing concepts of sustainable living to the individuals who make up communities, and creating sustainable new forms of co-operative development planning. It is proposed that each local authority “enter into a dialogue with its citizens, local organizations and private enterprises and adopt ‘a Local Agenda 21’” action plan

(United Nations 1993, Agenda 21, Section 28.3). The chapter is the briefest and possibly most concise in the entire Agenda 21, and like the others, is founded on a 'Basis for Action' which states, in part:

Local authorities construct, operate and maintain economic, social and environmental infrastructure, oversee planning processes, establish local environmental policies and regulations, and assist in implementing national and sub-national environmental policies. As the level of governance closest to the people, they play a vital role in educating, mobilising and responding to the public to promote sustainable development (United Nations, 1993, Agenda 21, Section 28.1).

The chapter lists four objectives, three of them with specific milestones. By 1993 the international community should have initiated consultations to increase co-operation between and among local authorities, by 1994 representatives of local authorities should have increased levels of co-operation to enhance exchange of information between and among local authorities, and by 1996 most local authorities in each country should have consulted with their communities and gained consensus on local Agenda 21 plans for their community. In addition all local authorities should have implemented and monitored programs aimed at ensuring that women and youth are represented in decision-making, planning and implementation processes (United Nations 1993, Agenda 21, Section 28.2).

The range of national responses to those proposed deadlines is well illustrated in the survey of eight European nations conducted by Lafferty and Eckerberg (1998). They found that three countries qualified to be what the authors termed 'pioneers', two were listed as 'adaptors' and three as 'late-comers'. In all cases there was uncertainty as to what 'a local Agenda 21' actually constituted, and inconsistency in both the efforts of local authorities to engage in the process of establishing one and national government assessments of when it had been accomplished.

In Australia the response to LA21 has been mixed. In response to perceived uncertainty, confusion or, in some cases, councils taking the 'soft' approach to considering that any pre-Rio steps towards environmental improvement qualified a local authority to claim implementation of LA21, ICLEI created a Local Agenda 21

Campaign, designed to generate tangible results. Councils are required to commit to completing five milestones marking their progress towards meeting the campaign objectives:

- establish a multi-sector committee of representatives to develop and implement an LA21;
- complete a sustainability audit of social, economic and environmental conditions and trends in the community;
- conduct a community review of the audit to produce a prioritized sustainable community vision for the future;
- implement an LA21 action plan which identified goals, priorities, measurable targets, roles and responsibilities, funding sources, and work activities; and
- enact community-based monitoring and annual evaluation and community progress reporting on achieving the LA21 action plan, using suitable indicators (ICLEI 2004, p.2).

By the late 1990s the Australian government had dropped 'Ecologically' from its ESD strategy. There was no media campaign nor any educational initiatives to take the Agenda 21 concepts to the broader community. Eight years after councils were to have completed an LA21 Action Plan only 80 municipalities have completed such a plan in explicit terms, and in Tasmania (while a number of Councils attended LA21 workshops run by the Sustainable Communities Research Group, University of Tasmania in 2002) few if any have official LA21 plans in place (Stratford, pers. comm. 2004). The Australian situation reflects that in Europe and perhaps globally. Many reasons have been proposed for the failure of Agenda 21 to impact effectively on local practices, but there are some common themes. Presenting a national government perspective, Upton (2001, p.7) suggested that nations do not have a long history of co-operation on a wide range of issues, and that the lack of a clear overarching framework left many nations uncertain about how to proceed and if others would. Desai (2001, p.22), an official of the United Nations, shares another of Upton's beliefs - that a lack of financial, human and technical resources made progress difficult for the poorer nations, but feels that in the industrialized countries progress depended greatly upon the national government prioritising implementation of local Agenda 21 planning. From the local community point of view, Elias (2001, p.31) concurs on the issue of lack of resources in poorer nations, suggesting also that

a lack of peace and security contributes to their lack of progress in implementing action plans, and feels that in all countries there has been a lack of public involvement in the entire process. Too few people know much about Agenda 21 for it to have advanced the concept of ecologically sustainable development and empowered them to help their local community to take more holistic decisions.

5.4 Cities for Climate Protection™ Program

During the 1980s there was increasing debate amongst the international scientific community about the rise in production of what became referred to as greenhouse gases (see Section 1.1.1) and their potential to contribute to global climate change. International concern led to the formation of the International Panel on Climate Change in 1988. Participating nations committed to the preparation of a National Greenhouse Response Strategy (NGRS), endorsed in Australia in 1992, when Australian Government agreed to an interim planning target to reduce greenhouse gas emissions by 20 per cent by 2005, based on 1988 levels. One of the priority measures in the NGRS was “increased energy efficiency within the residential and commercial sectors through energy labelling and minimum energy performance standards” (Hobart City Council 2001, p.9). At the 1992 Earth Summit 165 governments, including Australia, signed the United Nation Framework Convention on Climate Change. The 36 (mostly developed) countries listed in Annex I of the Convention committed to a modified goal of reducing greenhouse gas emissions to 1990 levels by 2000. By 1994 a review of Australia’s actions found this target unlikely to be met, as other nations concluded of their own measures (DPIWE 1999).

In 1993 ICLEI established the Cities for Climate Protection™ (CCP) campaign, as mentioned in Section 5.2. The campaign followed on from ICLEI’s Urban CO₂ Reduction Project (1991-1993), in which a number of cities in North America and Europe developed municipal planning frameworks for greenhouse gas reduction and strategic energy management. The experience gained led to the CCP five-milestone approach (which mirrors the five milestones used in the LA21 campaign), and also resulted in the development of CCP Greenhouse Gas Emissions Software to simplify the steps of conducting emissions analysis, evaluating emissions reduction strategies best suited to the community, and monitoring success of the chosen strategy (Commonwealth of Australia 1999).

In 1997 the Kyoto Protocol was prepared by the parties to the 1992 Climate Change Convention as a means to strengthen their commitment to that convention in light of the difficulties they were experiencing meeting its voluntary deadlines within a decade. Twenty-five of the industrialized nations' governments agreed to an overall 5.2 per cent reduction in 1990 emission levels by the years 2008-2012, although individual targets were negotiated by different parties. The largest gross contributor to greenhouse gas production, the United States, has refused to sign. So too has Australia, now the largest per capita producer (Turton 2004, p.vi), despite having been one of only three nations to negotiate an increase in emissions levels – of eight per cent above 1990 levels – along with Iceland's 10 per cent and Norway's one per cent (DPIWE 1999). However, in November 1997 the Australian Federal Government did announce a program to reduce greenhouse gas emissions, to be administered and funded by a newly established Australian Greenhouse Office (AGO) (Commonwealth of Australia 1999, p.4). The federal, state and territory governments co-operated to prepare the National Greenhouse Strategy, which was launched in 1998. Again one of the priority measures was implementation of efficiency standards for residential and commercial buildings and domestic commercial and industrial equipment, and another was for the establishment of a household greenhouse action plan. In that same year the AGO entered into a partnership with ICLEI to establish the Cities for Climate Protection™ Australia Program, to be delivered by Environs Australia, the local government network acting as ICLEI's agent. Initially established as a pilot program involving 29 councils, the campaign has seen a progressive expansion to the 196 councils involved in 2004. In Tasmania, Hobart City Council joined the program in 1999, as will be elaborated upon in Section 5.5. Subsequently two other major urban local government areas, Glenorchy and Brighton, have signed on.

The five-step process to which participating councils commit consists of:

- Milestone 1: quantify the current level of greenhouse gas emissions within the municipality and prepare a forecast of expected growth;
- Milestone 2: set an emissions reduction goal;
- Milestone 3: prepare a Local Action Plan of measures to achieve the goal;
- Milestone 4: implement the Local Action Plan; and

- Milestone 5: monitor and report on the implementation of the plan (Commonwealth of Australia 1999, p.7).

Nationally, different councils evolved various keynote strategies which they considered would most effectively reduce a major quantity of their greenhouse gas emissions. Thus, for example, one council focused on reducing transport emissions through car pooling, while another operates a green waste recycling program producing compost for household use. There have been a few energy efficiency strategies, with one being particularly notable – that of the Newcastle City Council, which is described in some detail in Section 5.5.

The budgetary breakdown reveals that in the year 2001/2002 the funding allocation from the AGO to the community sector was divided into six categories: transport, residential, commercial/industrial, waste and other. Total community sector funding made up 30 per cent of the total CCP™ actions expenditure and provided 35 per cent of the total abatement gained from implementing these actions. Fourteen per cent of the community sector budget was invested in residential programs (up from just two per cent in 1999/2000), delivering 63 per cent of all community sector abatement (AGO 2002, p.12). Nationwide, corporate sector carbon dioxide emissions reductions totalled 434,000 tonnes in 2001/2002, and community sector reductions were 230,000 tonnes (of which 146,000 were residential). The point is made that in addition to reductions in greenhouse gases there are other community benefits, including a reduction in required landfill space, improved air quality and that energy efficiency measures result in reduced electricity bills which benefit disadvantaged groups in particular. It could be added that this last also results in improved thermal comfort for residents, a matter of concern for residents in poor housing.

5.5 A City Council Energy Efficiency Study

Mention was made in Section 5.4 of the City of Newcastle's three programs engaged upon as part of its Third Milestone Report. Through its service unit, the Australian Municipal Energy Improvement Facility (AMEIF), the council partnered with the National Solar Architecture Research Unit (SOLARCH) at the University of New South Wales, and EnergyAustralia.

Third Milestone activities included:

- (1) Residential Energy Monitoring Program (REMP) – monitoring the electricity consumption of five households before and after comprehensive energy audits and energy efficiency retrofits. Retrofit costs ranged from \$224 to \$3372 (averaging \$1500), with two houses receiving major hot water system (HWS) retrofits (one to a solar HWS and one to a heat pump hot HWS). Electricity consumption logging continued for six months after the retrofit and revealed an average decrease of 17 per cent and a total annual saving of 9.81 tonnes of carbon dioxide.
- (2) Greenpower Retrofit Exchange Program (GREP) – combining signing up participants to Greenpower electricity in conjunction with implementing a range of household energy efficient retrofits and changes of practice. The seven families saved a total of 30 tonnes of carbon dioxide, with findings suggesting that under existing tariff structures signing up to 50 per cent Greenpower would have only minor financial impact on householders.
- (3) Household Energy Education Program (HEEP) – five families were surveyed for home energy and water habits, were involved in a participant-led energy smart workshop, given good energy behaviour tasks and monitoring and gave feedback. Savings of over seven tonnes annually of carbon dioxide were achieved.

Of particular note in the REMP results was the amount of savings both financial and in reduced carbon dioxide emissions attributed to improving hot water efficiency, especially when improving the HWS itself. Whereas the change in electricity consumption related to other retrofits in the houses produced reductions in electricity consumption of 9-13 per cent (and one increase of 40 per cent due to an extra resident and a new air conditioner), the figures ranged from eight to 68 per cent with an average of 37 per cent (and even the house which gained a resident improved 54 per cent). As described above, two of the houses had major HWS retrofits which resulted in the highest savings, but with payback periods over 10 years, while the other three homes averaged 6.5 year payback periods for AAA showerheads, tap aerators and, in one case a thermal blanket for the HWS. On the other hand it was felt that in a temperate climate like Newcastle's the value of installation of insulation could not be quantified in terms of greenhouse gas emission reduction, resulting mainly in gains in thermal comfort for the residents at quite high cost (AMEIF 2001).

The aim of GREP was to show that an energy audit and a basic retrofit to the value of \$200 would save enough money to allow a family to purchase a Greenpower product (electricity from a renewable energy source). Results showed that, provided only 50 per cent Greenpower was purchased, families would probably make a small financial gain, but the emission reductions per household were higher than observed in REMP, despite the families all having quite high awareness of sustainable living and energy efficiency issues before entering the program.

The smart household energy workshop conducted as part of HEEP covered information on typical household energy and water bills, appliances, hot water and space heating and cooling. Results indicated that improved awareness did translate into energy efficient behavioural gains, although there was considerable variation in uptake, with a suggestion that promulgating ideas to young children at school and having them bring the approaches home to the parents might be a better way.

The City of Newcastle projects highlighted the gains possible in residential energy efficiency by simple retrofitting exercises, educational workshops to raise residents' awareness of issues, and in particular, of the importance of having an efficient hot water system.

5.6 Hobart City Council

The Hobart City Council (HCC) endorsed the following environmental policy in 1996:

1. Protect and enhance the social, cultural, ecological and aesthetic values of Hobart to ensure that it is a desirable place to live and visit, both now and in the future.
2. Ensure that Council complies with relevant environmental legislation and satisfies community expectations regarding environmental management.
3. Promote community participation in the sustainable management of resources, and community awareness of environmental processes and issues.
4. Integrate development and conservation in a manner that ensures a sustainable future for Hobart.
5. Minimise the detrimental impact of human activities on the environment.
6. Promote the efficient and sustainable use of resources including the reduction and re-use of by-products.

7. Safeguard the ability of local species and ecosystems to respond to change by maintaining ecological processes and genetic diversity.
8. Ensure the on-going monitoring and assessment of environmental indicators in order to evaluate the impact of management strategies (Hobart City Council 1998).

In 1997 the Resource Management and Planning Scheme directed the State Government to produce a State of the Environment Report for Tasmania, and in 1998 the HCC produced one for its municipality. Continuing its record of being the first municipality in Tasmania to incorporate new environmental initiatives into its approach to governance (with the exception of Local Agenda 21 participation), HCC joined the CCP™ program in July 1999 and committed to reducing its corporate greenhouse emissions by 70 per cent and community emissions by 20 per cent by 2010. As part of the process HCC produced a Corporate and Community Local Action Plan (LAP) in 2001 to delineate its strategy for achieving these goals. Council already had some initiatives in place, including the release of its 'Energy Efficiency Design Guidelines', more recently updated (Hobart City Council, May 2003). As a part of the LAP, Council established a partnership with Cool Communities, an initiative of the AGO Community Partnership Program (the office which delivers CCP). Cool Communities was established in 2001 and is delivered in association with non-government organisations in each State and Territory. As part of its Strategic Plan 2001-2005, HCC has a commitment to increase energy efficiency, expressed in two clauses:

- 6.1.6 Develop an energy efficiency strategy for Council's corporate activities.
- 6.1.8 Develop programs and initiatives for energy efficiencies for development in conjunction with other stakeholders (Hobart City Council 2001, p.11).

In its LAP, HCC also recognises that when Basslink comes on-line Tasmania will no longer be able to claim that its electricity is all renewably sourced, and that it will be necessary for Council to be prepared to view differently, for example, street-lighting and buildings, in terms of energy consumption and greenhouse gas emissions from electricity generation (HCC 2001, p.12).

In the section of the LAP dealing with residential sector emissions, two of the listed objectives are:

- to actively pursue partnership projects and work collaboratively with the residential sectors and key stakeholders to reduce current and potential greenhouse gas emissions and energy consumption, including wood fires as a domestic heating source; and
- to actively promote, to the community, Council's Energy Efficiency Guidelines to reduce energy consumption and associated greenhouse gas emissions (HCC 2001, p.23).

Knowing that Council had these objectives in mind, the Sustainable Communities Research Group in the School of Geography and Environmental Studies at the University of Tasmania approached HCC seeking to form a partnership in which HCC would fund a research project on energy efficiency. That partnership resulted in a case study on retrofitting for energy efficiency and equity outcomes described in detail in Chapter 6.

5.7 Summary

Despite the difficulties of seeking consensus among large numbers of nations on anything, due to the diversity of cultures and influence of powerful lobby groups, a remarkable level of agreement appears to have been attained globally since 1987 on the need to reduce human impacts on the environment and the ecosystems of the world. However, some of the actions in response to this need have been mixed, especially with the multiple attempts to achieve a set level of greenhouse gas reductions, and then to renegotiate the level. In a reflection on the follow-up Earth Summit+5 held in 1997, the UN Under-Secretary for Economic and Social Affairs noted that the gap between rich and poor nations continues to grow, exacerbating the need for an enabling economic environment with the developed countries actively supporting the less developed towards sustainability (Desai 2001, p.28). However the governments in developed countries are themselves only taking halting steps on the path to sustainability. In Australia some useful initiatives and objectives have been pronounced, but there is evidence in the area of energy efficiency that achieving results can take a long time. As noted in Section 5.4, the National Greenhouse Response Strategy in 1992 listed as one of its priorities the need for improved energy efficiency in the residential sector through energy labelling and minimum energy performance standards. They remained an undelivered and re-stated priority when

the National Greenhouse Strategy was launched in 1998. Not until 2003 did Tasmania and Victoria mandate minimum energy performance standards for new homes. At local government level, the consultation with the community and drafting of a Local Agenda 21 action plan was to have been completed by most councils in the nation by 1996, but none attempted one in Tasmania until 1998, and few have followed.

The most positive aspect of all the planning described in this chapter is possibly the evidence that when action is taken at local government level it can produce rapid results. The reduction in greenhouse gas emissions achieved by councils around the nation is impressive, and it is possible to bring concepts of sustainable living to people quite rapidly with workshops. In the article referred to in section questioning awareness levels of Agenda 21, Elias (2001) posits that there are three main barriers slowing the move to a sustainable society: lack of peace and security, lack of resources, and lack of public involvement and access to information. If all councils participated and if they were adequately resourced to impart the concepts to the majority of their citizens, then they could effectively achieve the part of the statement quoted in Section 5.3: “As the level of governance closest to the people, they play a vital role in educating, mobilising and responding to the public to promote sustainable development.” Currently a major weakness in the federal strategy of LA21 delivery is that it relies upon local governments to sign on, which nationally the majority has still failed to do, with the Tasmanian rate the poorest in the country. A second weakness in terms of delivering outcomes to people is that the residents are captive to the approach determined by their council, what the council chooses to focus on and how hard it attempts to market its program. The Federal Government has not prioritised LA21 and if it doesn’t resource councils adequately the program is little more than a lip-service contribution to empowering local communities.

Chapter 6 examines a case study of a retrofit to improve the energy efficiency of a home in a project sponsored by local government.

Thus I found myself in familiar stringybark country, but in a plastic-clad house on stumps in far north-west Tasmania. The landlord had recently bulldozed the windbreak on the south and west sides of its small allotment, leaving the house exposed to the south-westerly gales across the dairy paddocks. The wind rushed over, under and around the bare building, the pet goat huddled shivering in her little house and her eyes went an unhealthy cloudy colour. It was January, and a little unnerving. In recompense I had hot water almost at boiling point, but a power bill to match. The next year I was fortunate to secure 40 hectares of sheltered north-facing land (this time it was intentional, unlike at Uraidla) near the hamlet of Mengha and hurried a cabin together before winter. Piece by piece, over the next few years, I assembled a hybrid renewable energy system. The solar panel, micro-hydro turbine and small wind-generator fed the re-cycled batteries, the slow-combustion stove had a water jacket which fed the hot water system, but above all the timber cabin feasted on the sun through its north-facing windows. It was humble, but heartening – a happy 'thermal comfort' result (augmented by a tiny wood-heater).



CHAPTER 6: CASE STUDY: 'THE TAROONA HOUSE'

6.1 Introduction

In March 2002 Hobart City Council (HCC) offered one of its occupied homes for use in a co-operative research study with the Sustainable Communities Research Group (SCRG) in the School of Geography and Environmental Studies at the University of Tasmania. The aim of the case study, to monitor the change in energy efficiency as a result of a retrofit to an occupied house, dovetailed with Council's commitment to the Cities for Climate Protection milestones described in sections 5.4 and 5.6. Council was also offering a budget of \$5000 for works to be carried out and materials required to conduct the retrofit. Originally the study, including modifications to the home, was to be completed within one year, but subsequently this was extended to two years, which enabled collection of baseline data from the home for a full cycle of seasons, carrying out of alterations, and then monitoring for another full cycle of seasons. Given that the title of this study implies a focus on inexpensive retrofitting, a subjective term, it was felt that \$2000 might be a more appropriate self-imposed limit, although this target did not dominate the choice of retrofitting options. The inability to raise \$2000 in an emergency is one of the definitions of poverty in a report on economic wellbeing in Tasmania (DHHS 2001), and provides a convenient marker of affordability for retrofitting projects aimed in particular at people who need their homes improved for health reasons.

Initially the intention was to conduct what Stake (2000) defines as an intrinsic and instrumental case study, examining one particular home to determine the intrinsic value of the retrofit to this house, while providing insight into the broader issue of improving energy efficiency in the existing building stock of Tasmania, at low cost to home owners. The fact that HCC was the landlord dovetailed with broader intentions for the study to investigate both the role of local government (as outlined in 5.6), and improving residential energy efficiency at minimal cost, as financially disadvantaged groups spend disproportionately higher amounts of their income on housing as well as on their energy bills (Pye 1996, p.3, Burningham & Thrush 2003, p.519). Many such disadvantaged people are renting, which discourages them from making changes to their housing, and there is no incentive for landlords to make improvements to energy efficiency.

Late in the investigation an opportunity arose for me to conduct energy audits of student housing for the Tasmanian University Union. This work enabled me to include in the thesis observations of a number of rental situations in the HCC area, almost all of which involved older homes. The thesis thus became informed by what has been called a collective case study (Stake 2000).

6.2 'The Taroona House'

The HCC's Taroona house (Figure 6.1) is an older dwelling (Council is uncertain of its construction date), of timber-framed construction and clad in weatherboards. The house has been constructed in the Gothic-revival style, may date to the 1870s (R. Kellaway, personal communication, Nov. 2002), and is heritage-listed under the *Cultural Heritage Amendment Act 1997*. Due to Hobart home occupancy being lower in the 1870s than in the 1850s because of the Victorian gold-rush, a slump in the building industry meant that Hobart has very few examples of the later phases of Gothic Revival construction (Scott 1959, p.152). The home has a central east-west hallway separating the kitchen and lounge living spaces on the north side from the two bedrooms and bathroom on the south side. The house plan in Appendix 3 shows the lay-out of the rooms. As it faces north, the building is well-oriented for solar gain, however there are *Cupressus macrocarpa* trees on the north side of the house, three of which are in excess of 20 metres tall and within 6 to 15 metres of the front wall, along with a large number of *Pinus radiata*, *Cupressus sempervirens*, *Cedrus deodar* and *Cedrus atlantica* in an arc from the north-east to the north-west and all within 35 metres of the house and up to 20 metres tall. These conifers form a particularly dense stand in the north-west and western sectors and are also heritage-listed. An aerial view of the house amidst the conifers is in Appendix 3. The house is rented by a family of two adults and three young children, who have lived there since early 2001.

6.3 Retrofitting Options

As an older timber-framed weatherboard house, the Taroona house was a prime candidate for infiltration reduction. While its weatherboards were largely in good repair and quite well sealed, the inner envelope of floor, walls and ceiling was in places poorly sealed. Worst were the gaps where walls met floor, particularly in the

kitchen, and also the gaps in the floor beneath built-in kitchen cupboards, one of which lacked a floor-level kick-board on the side. Major draughts could be felt on windy days.



Figure 6.1 The Taroona house

The house lacked any form of fitted insulation, but as no structural alterations were contemplated (emphasis on low-cost improvements), nor could they be (heritage-listed house), the walls could not be insulated. The ceiling of the whole house was readily able to be insulated because of the high hip-roof above it. Due to substantial slope of the land to the east, as can be seen in the picture of the house, much of the floor is substantially above ground level. It is not effectively enclosed and is prone to substantial heat loss from free air circulation. Access to the space beneath the kitchen and bathroom at the western end of the house is denied by a dwarf sandstone wall. Thus almost three-quarters of the under-floor area was readily accessible for fitting under-floor insulation. There were flimsy lace curtains on just three of the windows with negligible ability to contain radiant heat within the house at night. This failing could be redressed by fitting heavy lined curtains to all windows.

As the house is heritage-listed, it was not possible to consider any structural modifications to the building to enhance solar gain, although this was beyond consideration due to the intention to strictly minimise costs. Because all trees on the property are also heritage-listed, the 25-metre tall *Cupressus macrocarpa* trees immediately to the north of the house were not eligible for removal in the interests of improving solar gain (but this too would have been another costly exercise).

Finally, increasing the thermal mass of the structure was not a retrofitting option for the same two reasons of cost and heritage-listing. Thus it was decided to target infiltration reduction and insulation improvement.

It should be mentioned that the hot water system was enclosed by a close-fitting cupboard in the bathroom.

6.4 Baseline Monitoring

Monitoring of the temperatures in the house prior to making any changes commenced on 6th June 2002 using Hobo™ dataloggers, which are matchbox-sized electronic temperature recorders capable of recording temperatures for extended periods determined by the frequency of readings required. The dataloggers were located in the kitchen, lounge and master bedroom at a height of about 1600mm, safely out of reach of small children, and on top of the door architrave in the children's bedroom (even further out of reach). The location points of the dataloggers are shown on the house plan in Appendix 3.

The dataloggers were initially set to record quarter-hourly temperature readings, which they could do for 19 days. From 2nd July the setting was altered to hourly readings, enabling the loggers to collect data for 75 days, after which they were removed to download the data at the University of Tasmania, before being returned to their same positions in the house – an operation which could be accomplished in about two hours. This baseline monitoring continued until the house was retrofitted in June 2003, and monitoring was continuous through the retrofit and for the following 12 months until 22nd June 2004.

In order to compare internal house temperatures with external ones, a later model datalogger of the same type was installed in a climatology screen on the south side of the house on 14th November 2002. This logger had the capacity to record 330 days of hourly temperature readings and was run until house monitoring ceased in June 2004, requiring only one intermediate download.

6.5 The Retrofit

Initially I conducted an audit of the integrity of the building envelope (Table 6.1) in order to assess the state of the structure and requirements for materials to reduce infiltration. Internal doors and curtain and pelmet requirements were also assessed. Quotes were obtained for these materials and for the timber and assembly of pelmets for all windows. Quotes were then submitted to council and suppliers selected.

Table 6.1: Audit of building envelope, internal door, curtain and pelmet requirements

1. EXTERNAL DOORS (Room and Type)		QUALITY OF SEAL		
		Bottom	Top and Sides	Middle
Hall (West entrance) - solid door		fitted seal	poor	-
Hall (East entrance) - solid door			poor	-
Lounge (North wall) - French doors		fitted seal	poor	poor

2. WINDOWS (Room and Dimensions)		TYPE	QUALITY OF SEAL
S	Children's bedrom - 860W x 1700D	double-hung sash	fair
O	Bathroom - 780W x 520D	fixed pane	good
U			
T			
H			
E	Master bedroom - bay: 850Wx1700D	double-hung sash	jammed with a gap
A	SE: 750Wx1700D	double-hung sash	poor
S	NE: 750Wx1700D	double-hung sash	jammed with a gap
T	Lounge - 840W x 1700D	double-hung sash	fair
N	Kitchen - W: 860W x 1700D	double-hung sash	jammed with a gap
O	E: 860W x 1700D	double-hung sash	no sashes& big gaps
R	Lounge - bay: 2@ 820W x 1700D	double-hung sash	poor
T	W: 420W x 1700D	fixed pane	good
H	E: 420W x 1700D	fixed pane	good
W	Hall - 1470W x 760D	fixed pane	good
E			
S			
T			

3. EXTERNAL WALLS	WEATHERBOARD GAPS(m)	GAPS AROUND PIPES(cm)
SOUTH	2m total gap-length	-
EAST	-	-
NORTH	5m total	-
WEST	1m of gaps	65mm waste-water
4. FLOORS	GAPS	REQUIREMENT
KITCHEN	skirting /cupboard	12mm Pine Quad. 1 tube silicone putty/silicone
LOUNGE	plug unusedTV antenna hole	
MASTER BEDROOM	-	-
CHILDREN'S BEDROOM	-	-
HALL	-	-
5. OTHER OPENINGS	TYPE	REQUIREMENT
KITCHEN	chimney	steel plate (bottom)
LOUNGE	-	-
MASTER BEDROOM	chimney - shared	steel plate at top of chimney
CHILDREN'S BEDROOM	chimney - shared	
HALL	-	-
6. INTERNAL DOORS	PRESENT/ABSENT	QUALITY OF SEAL
KITCHEN - To Hall	absent (under house)	non-existent
- To Lounge	present (no jambs)	non-existent
LOUNGE - To Hall	present	fair
7. CURTAINS/PELMETS	WINDOW DIMENSIONS	DIMENSIONS FOR CURTAINS
KITCHEN	2000W x 1700D	2200W x 2000D
LOUNGE	bay: 2500Wx1700D	2600W x 2000D
	Fr.Door1470Wx2030	1620W x 2100D
	840W x 1700D	1040W x 1700D
	door: 2210Wx2000D	2400W x 2070D
MASTER BEDROOM	bay: 2350Wx1700D	2500W x 2000D
CHILDREN'S BEDROOM	840W x 1700D	1040W x 1700D
BATHROOM	840W x 1700D	1040W x 1700D

Retrofit work commenced on June 13, 2003 and was completed within a week. Hobart City Council provided a tradesman who fitted weatherstripping to the external doors (Figure 6.2) and to the internal doors in the kitchen and lounge. The door from the kitchen to the hallway had been damaged and removed prior to the current occupants taking up residence. It was repaired in the week before the retrofit and the tradesman re-fitted it.



(a) Pre-retrofit damaged weatherstrip



(b) New weatherstrip around edges

Figure 6.2: Weatherstripping on lounge French doors

His work also involved sealing all gaps in the inner building envelope described in section 6.3, fitting recently constructed pelmets to all the windows in the house (Figure 6.3 to Figure 6.5), and sealing off unused chimneys. This last was achieved by fitting a steel plate to the top of the chimney shared by the two bedrooms, and a steel plate to the bottom of the kitchen side of the one shared by the kitchen and lounge (Figure 6.6). (The lounge already had a woodheater fitted into the fireplace and fully sealed off.) The edges around the steel plate on top of the chimney were weatherproofed with lead flashing, and the edges of both steel plates were given a final seal with silicone to eliminate all draughts. The tradesman also assisted with the installation of heavy lined curtains to all windows in the house. The curtains had been provided by the Tasmanian University Union under an innovative hire scheme called a ‘curtain library’ (see section 6.8).

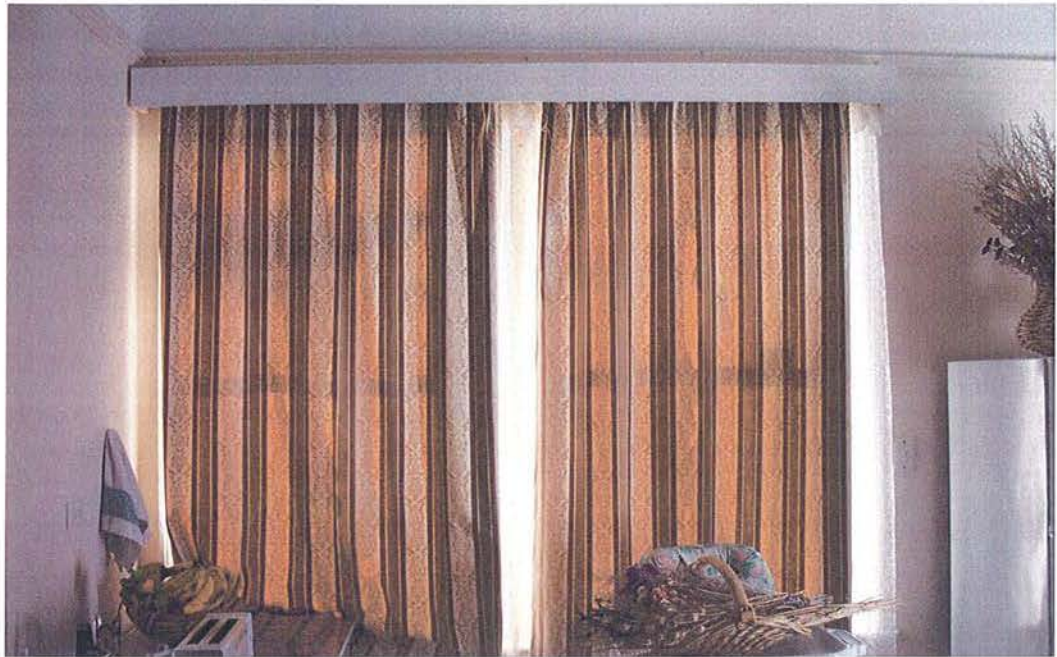


Figure 6.3: Lined kitchen curtains and new box pelmet

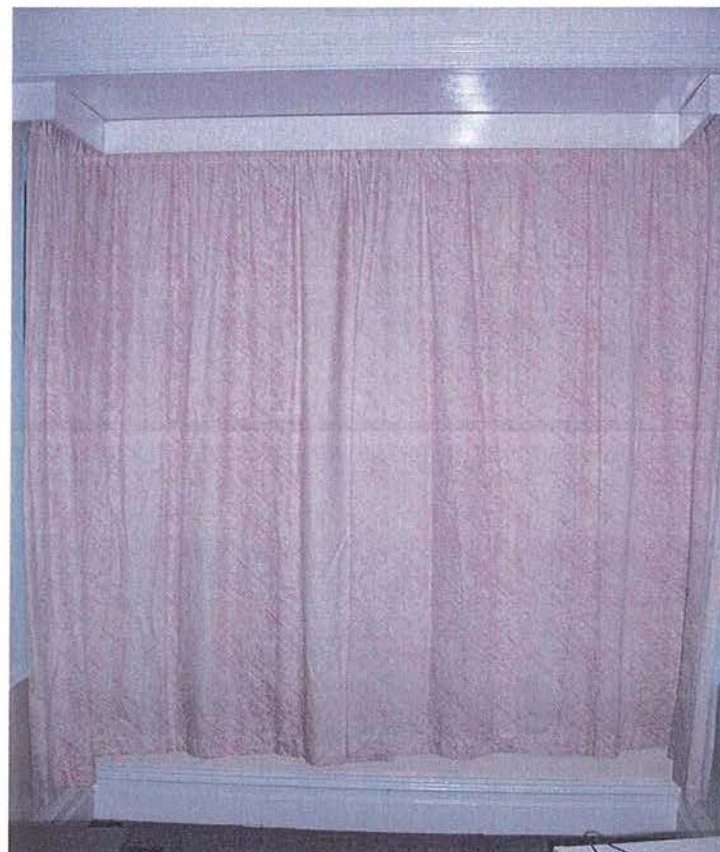


Figure 6.4: Lounge bay-window curtains with pelmet fitted to ceiling



Figure 6.5: Lounge French doors with box pelmet and curtains

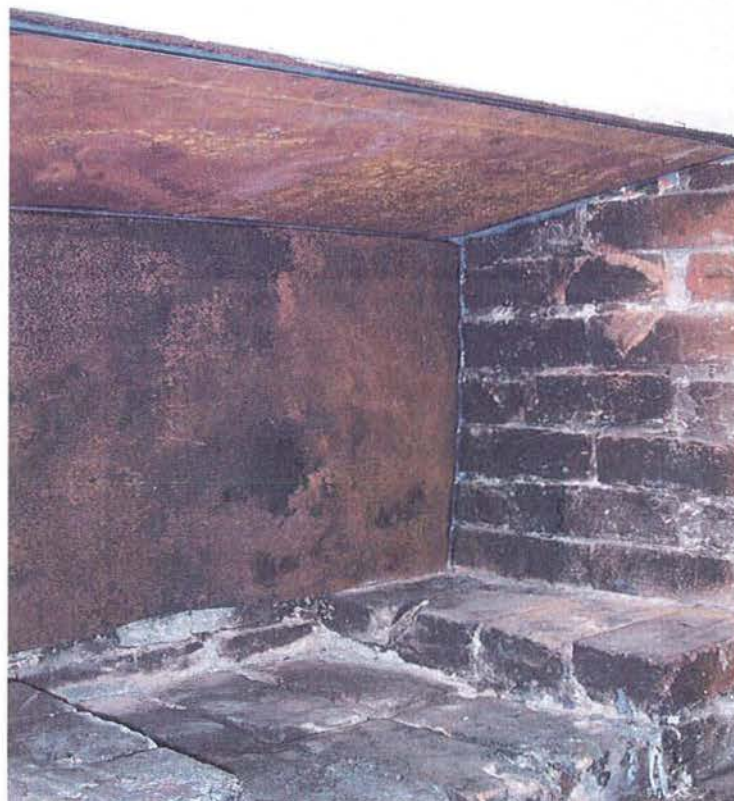


Figure 6.6: Kitchen chimney-base sealed with steel plate

On 17 June 2003 an insulation contractor fitted R3.8 insulation batts above the ceiling of the entire house, and below the accessible parts of the floor R1.5 batts were installed between the floor joists. Heavy-duty, rodent-proof, reflective foil laminate was stapled beneath the joists, sealing the batts in place with an enclosed air-gap. A summary of costs for the retrofit is in Table 6.2.

Table 6.2: Costs for retrofit of the Taroona house

Draught Reduction	Cost
Weatherstripping materials for external doors and windows were purchased	\$ 92
A kitchen door which had been removed was repaired and replaced	\$ 40
Steel plates were purchased and sealed on top of the bedroom chimney and at the bottom of the kitchen chimney	\$ 72
Silicone was purchased for application to gaps around skirting boards and in weatherboards	\$ 33
Wages for HCC tradesman	\$512
Insulation	
R3.8 pink batts were purchased and installed by the contractor in the ceiling, and R1.5 batts under the exposed elevated floor (and held in place with heavy-duty rodent-proof reflective foil)	\$1788
To improve heat retention at night, pine pelmets were constructed for all windows (painted & installed by Council)	\$ 385
Only 2 windows had curtains (thin ones) so a full set was obtained from the University curtain library (established Cool Communities Tasmania) for a nominal bond	\$ 20
Total Cost of Retrofit	\$2942

6.6 The Residents' Perspective

One cold day, shortly after the retrofit had been completed in June 2003, I went to the house to ask the residents if they had noticed any changes in living conditions since the alterations. The woman resident commented that she had already noticed some changes which surprised her. She said that in the previous two winters, 2001 and 2002 she had chilblains on her feet for several months from May onwards. They had returned in May 2003 but were gone within days of the completion of the retrofit. Even more surprising, she said, was the children's health. Whereas they had sniffles and colds almost continuously through the winters of 2001 and 2002, and then they went on to have a chest cold and one had asthma, in the week after the retrofit the chest cold which the eldest already had cleared up, and the others lost their sniffles. Everyone had noticed almost immediately that when they talked to each other the 'vapour trails' they were used to seeing weren't there anymore.

This feedback so soon after retrofitting was a welcome surprise in a cold month. It made the formal interview, (to be held in more than a year's time after monitoring had ended), something to relish. The reason for not conducting the final interview until after completion of monitoring was to enable the residents to experience the house over a year of seasons. In the final event, the interview with both parents revealed more of the same good news.

Health gains continue to be noticeable, with less frequent sickness and anyone who gets sick recovering more quickly than they used to, without chest infections. The bedrooms are warmer at night than previously, and the house holds its temperature better in summer. The improvements are easier to notice in winter than in summer. The house used to be noticeably draughty, especially in the kitchen but isn't now. The vapour trails visible when they spoke in winter had disappeared for some time, but were now back when they were in the bedrooms. In winter they used to run the woodheater in the lounge and it heated the room quickly, but the room cooled fast too if the heater died down. The woodheater was not good for one child who had asthma. After the retrofit they continued their pattern of going into the lounge after the evening meal and sitting by the fire. Some time later they felt that with the refitted door in the kitchen closing out the hallway they could stay in the kitchen. Now they spend most of their time in the evening in the kitchen, which heats up quickly with a little fan-heater. Often, after the children are in bed, the parents take

the fan-heater into the lounge and it heats it well and the room holds its heat. There used to be a great deal of condensation on the windows in the mornings but now there is much less. It used to be difficult to dry towels and tea towels, but now tea towels dry overnight and only the thickest towels are not quite dry. Mould previously appeared on items such as quilt covers and clothing in the clothes basket, but there has been no recurrence of mould on bedding or clothing. There had been mould on the bathroom ceiling and still is, but whereas there had been no mould in the bedrooms (apart from below a small roof leak above the children's ceiling), this last winter of 2004 there has been mould on the southern walls of both bedrooms.

Power bills do not seem to have changed, but they no longer have any expense for wood. Coming from Queensland where there were water meters, they considered they were quite environmentally conscious and owned a front-loading washing-machine. They were aware of the benefits of insulation as they had lived in an extreme climate with very hot summers and winters which were cold due to the altitude. Their house was not insulated and was unbearably hot in summer, so they had it done and noticed the benefits. In any house they may own in the future, the couple said they would definitely insulate the ceiling, and if they could afford it, the walls as well. They would recommend the retrofit changes done to the Tarooma house to anyone for improved livability, and especially for the health benefits.

6.7 Analysis of Results

This analysis is of temperature data and electricity consumption. In the month of the retrofit, June 2003, if the data for the kitchen are plotted against the external temperature data as in Figure 6.7 it can be seen that there was a major cold snap shortly after the draught-proofing was done, and that external temperatures were lower in the period after the completion of the retrofit than they had been before it.

Analysis of both sets of temperature data for the first and last 12 days of the month shows that while external minima dropped by an average of 3.6°C in the latter period, kitchen minima only declined by an average of 0.9°C. By analysing minimum temperatures any variations in heating behaviour are circumvented.

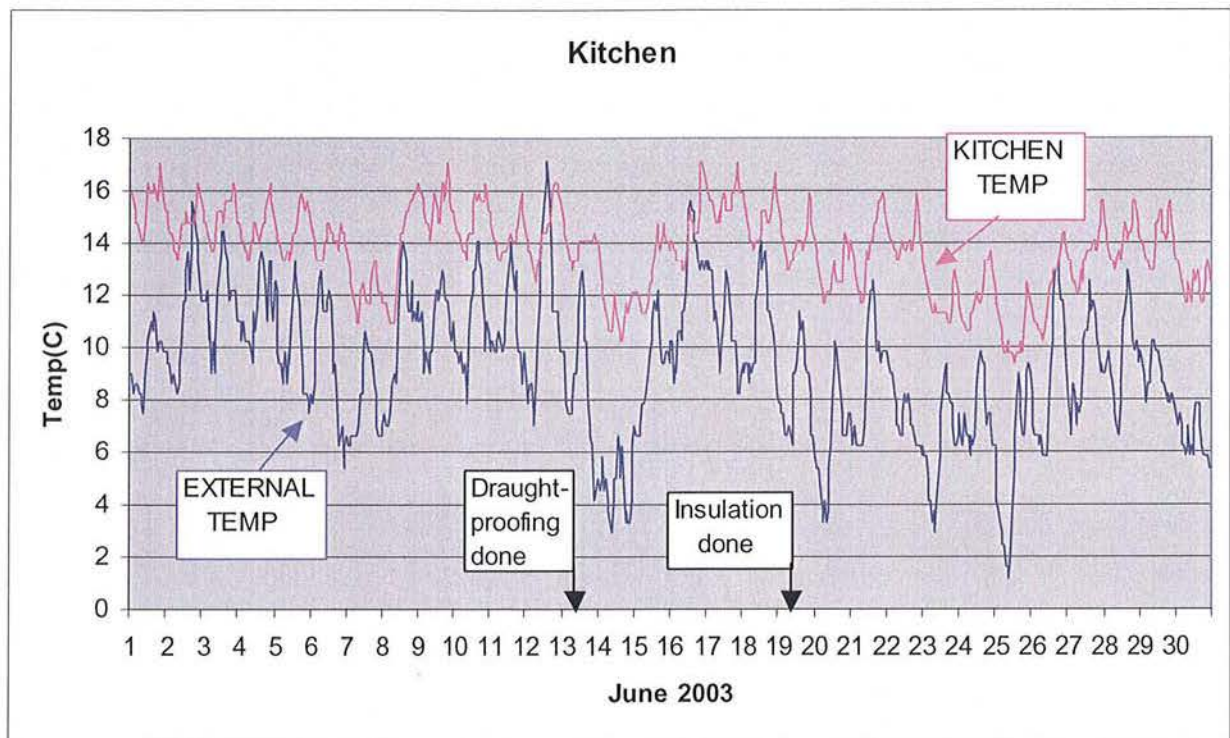


Figure 6.7: Kitchen and external temperatures during the retrofit month

The graph of the comparison between July 2002 and July 2003 for the lounge (Figure 6.8) shows conditions to have been notably warmer in the latter month. As the on-site external datalogger was not installed in July 2002, average temperature data from the Bureau of Meteorology station at Battery Point were used to compare external conditions. While the lounge was an average of 3.2°C warmer in July 2003, Bureau temperatures averaged 1.3°C less than in July 2002.

It is apparent that the woodheater was used more extensively in July 2003, but two pieces of anecdotal evidence are verified by the graph. In the latter interview the residents said that the lounge seemed to heat up more easily and to retain its heat better, and this seems borne out by nightly maxima in the lounge, given that external temperatures were lower in the July after the retrofit.

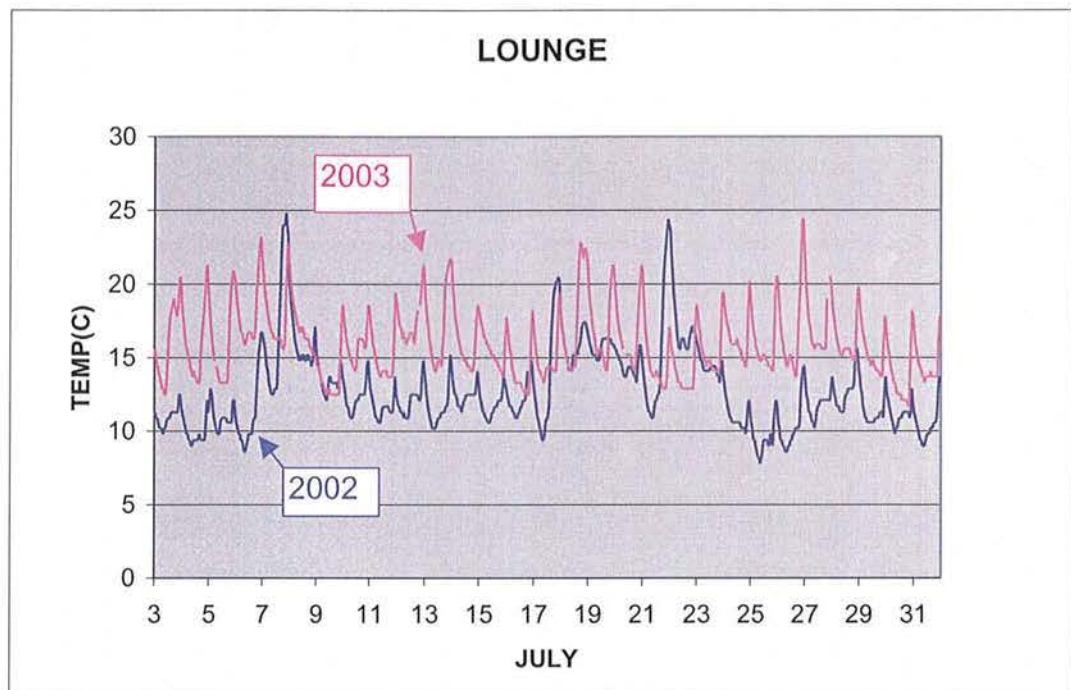


Figure 6.8: Lounge temperatures in July 2002 and 2003

The second point is that they said they had continued to inhabit the lounge for some time after the retrofit, and the fire appears to have been lit almost every night. As the amount of wood burnt is unknown due to the residents having made small random purchases of bagged wood from a service station, there is no way of knowing how much more energy efficient the lounge is, and how much of the benefit the residents may have had in increased thermal comfort or ‘take-back’ (see section 2.4). However, since they clearly were in the lounge each night, it ensures that the improved situation in the kitchen relative to outside after the retrofit noted in June 2003 above was not due to them changing their use of heating in the kitchen.

The comparison graph for the kitchen in July 2002 and July 2003 (Figure 6.9) shows the latter month to have been appreciably warmer in the kitchen. Analysis of the data indicates that the average temperature in the kitchen in July 2002 was 12.7°C and in July 2003 15.9°C, an improvement of 3.2°C (as in the heated lounge).

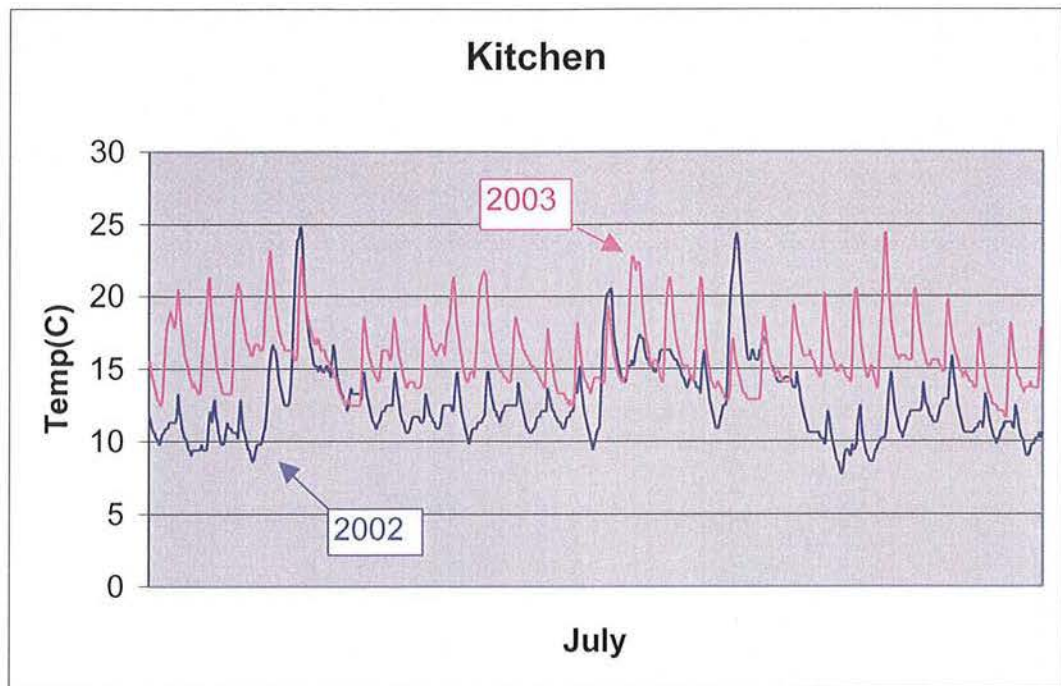


Figure 6.9: Kitchen temperatures in July 2002 and 2003

Thus the living spaces show identical gains in these months. It should be noted that the kitchen temperature in July 2003 barely averages the World Health Organization recommended minimum average temperature for an occupied room (section 2.3).

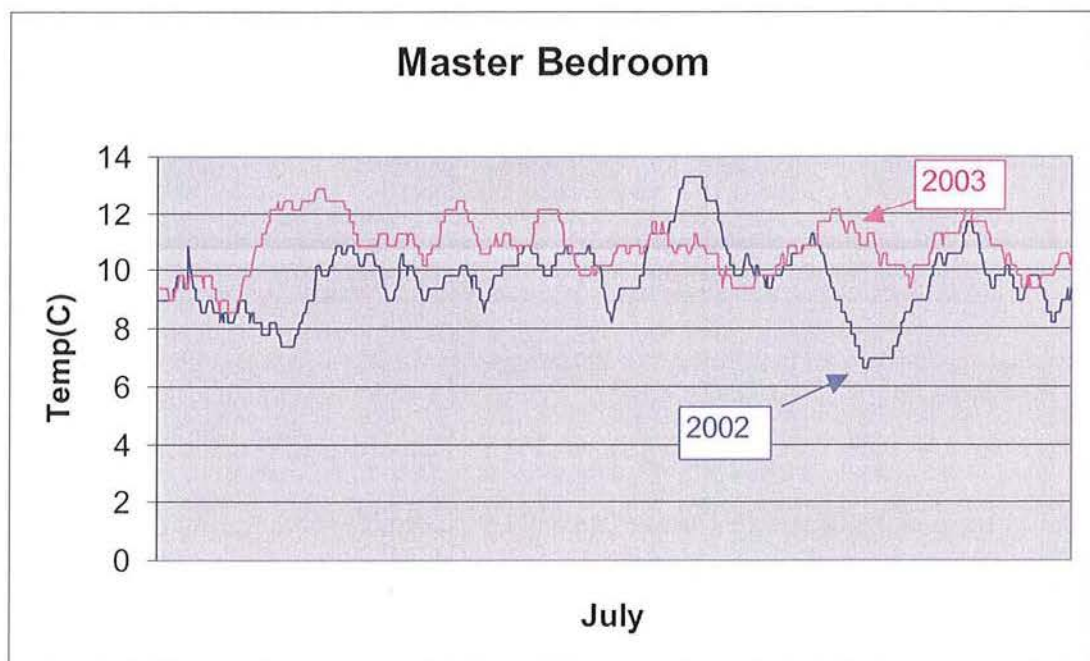


Figure 6.10: Master bedroom temperatures in July 2002 and 2003

To see what changes have occurred in the unheated bedrooms on the south side of the house, Figures 6.10 and 6.11 are comparison graphs for July 2002 and July 2003 in the master bedroom and children's bedroom respectively.

In the master bedroom the average temperature has increased from 9.7°C in July 2002 to 10.8°C in July 2003 despite the external average being 1.2°C lower in the latter month.

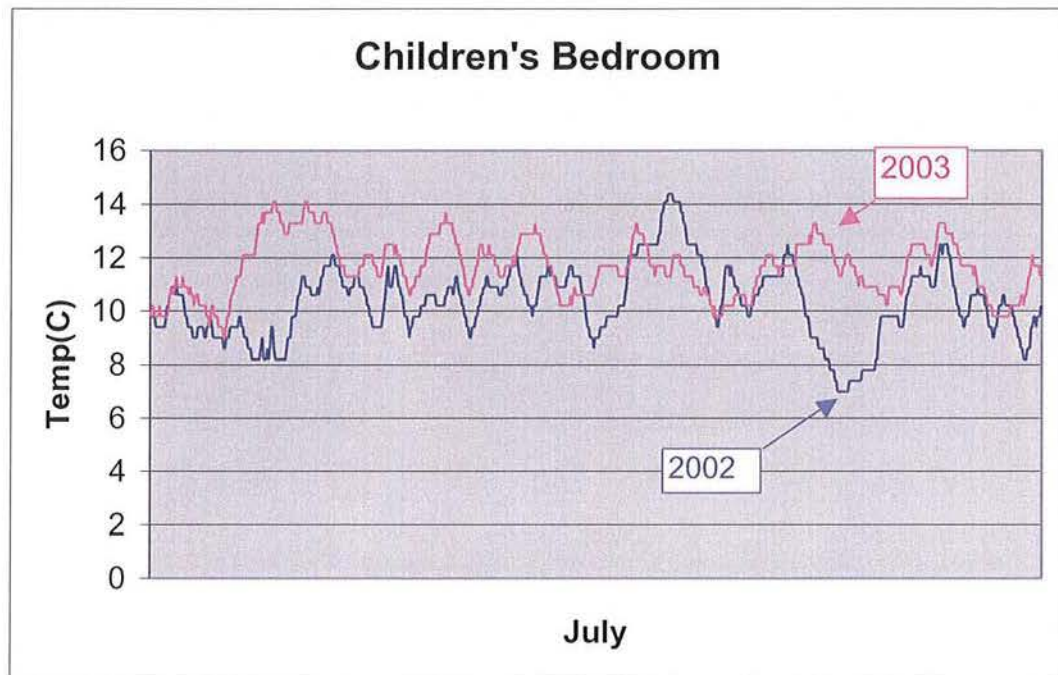


Figure 6.11: Children's bedroom temperatures in July 2002 and 2003

In the children's bedroom the July 2002 average temperature of 10.3°C has risen to 11.6°C in July 2003. To put the gains in these bedroom temperatures into perspective, it must be stated that both rooms are averaging considerably less than any recommended minimum average temperature for an inhabited space. When considered against external temperatures, the net gains in average temperature in the living areas are between 2.6°C and 4.5°C, while in the unheated bedrooms gains are a slightly more modest 2.5°C. A table of external average temperatures for all complete months of data collection from June 2002 to June 2004 is in Appendix 1. Further results in the form of comparison graphs for the months of February 2003 and 2004 are in Appendix 2. One additional improvement in thermal comfort to be seen in the graphs in Appendix 2 is that bedroom temperatures in summer are cooler, which may make conditions more comfortable for sleeping.

The electricity consumption figures for the period from 10 July 2002 to 12 July 2003 were compared with those from 13 July 2003 to 15 July 2004. In the latter 12 month period there were 9029 kWhr consumed, up from 8763 kWhr – an increase of three per cent. This rise could be accounted for by the information the residents gave in the interview about having begun to use the fan-heater in the kitchen to keep it warm at some stage after the retrofit, a habit they maintained until the time of the interview in September 2004. They also spoke of using the fan-heater to warm the lounge when they decided against using the woodheater in the winter of 2004, as it adversely affected one child who suffered from asthma. Balanced against this small increase in electricity consumption is the complete lack of expense for buying wood in the winter of 2004, an amount they could not guess at as they had previously bought small expensive amounts regularly through the winter of 2003.

For the residents the experienced gains in thermal comfort appear to have felt more significant than the results show, and their slight increase in electricity consumption was more than off-set by the savings from not buying wood, as the extra 266 kWhr would have cost \$36 if the entire increase was charged at the highest 2003 tariff rate.

This retrofit has been conducted with some constraints which limit its potential effectiveness. A retrofit would usually aim to improve solar gain at first without alterations to the building structure by the removal of vegetation which shaded the house from winter sun. The heritage listing of the site prohibited the removal of trees which in this case almost entirely block winter sun from entering the house. Heritage listing also meant that no structural changes could be made to the building, including the installation of wall insulation. This constraint did not impact on this study as wall insulation was considered a low priority due to its smaller returns in energy efficiency and given the self-imposed financial limit of approximately \$2000 on the retrofit (see 6.1).

Operating within the constraint of no tree removal, the relatively small increases observed in room temperature particularly in the unheated bedrooms on the southern side of the house are not unexpected. Indeed the gains of up to 4.5°C in the average temperature in the living areas are quite appreciable given that they are reliant upon room heating which is generally only conducted between 1700 hours and 2300 hours

(from analysis of evening room temperatures). With solar gain through the windows on sunny winter days, average living area temperatures could be expected to be significantly higher during the day and to some degree at night. Temperature reductions in the bedrooms in summer would also be more significant in houses exposed to more direct solar radiation.

Economic gains from the retrofit are mostly observed in the removal of the need to purchase wood to achieve thermal comfort, which more than outweighed the three per cent increase in electricity consumption due to increased use of a small fan-heater.

The most significant results from this study are from the improved health of the children in winter months in particular, and the increased feelings of well-being experienced by all family members about conditions in the house, especially in the living areas. The disappearance of mould from bedding and clothing is particularly important given the findings of section 2.3, in particular the connection between mould and respiratory problems, especially asthma. No price can be put on these gains.

The recent appearance of mould on the southern walls of the bedrooms is related to humidity. Relative humidity at the surface of materials needs to be kept below 80 per cent (Oreszczyn 1992, p.179). It would appear that the retrofit has lowered the relative humidity of the air in the bedrooms as a result of the temperature increase sufficiently to prevent the formation of mould on items of clothing. However, mould can grow on a wall even if the relative humidity of the air is less than 80 per cent because an outside wall has a higher relative humidity at its internal surface than does the bulk of the air in the room (p. 179). Oreszczyn adds that the reduction in temperature at the external wall means that the air can hold less moisture, so 70 per cent is the commonly quoted upper limit for relative humidity in rooms. The fact that the walls are uninsulated means the temperature difference between air and wall is greater, increasing both surface relative humidity and the likelihood of mould. Insulation in the south wall of the house could have kept the inner surface of the wall warmer, eliminating the possibility of conditions developing which were conducive to mould growth. Comparison of Bureau of Meteorology rainfall data for Taroona and three-month winter average temperatures for the closest station at Battery Point,

reveal that winter 2002 was both drier and warmer than average, reducing the likelihood of mould growth (Bureau of Meteorology 2004). In the winters of 2003 and 2004, Taroom had significantly above average rainfall, but temperatures were lower in the latter. Indeed, on-site external temperatures for June 2004 averaged over 2°C less than in June 2003, which, in combination with extended cloudy and rainy periods, provided suitable conditions for the promotion of mould growth. Thus, despite warmer room temperatures in the bedrooms after the retrofit, higher relative humidity and colder external wall temperatures in 2004 resulted in previously unreported mould growth.

6.8 Study-generated Flow-on Effects

The Australian Greenhouse Office (AGO) has run a nation-wide Cool Communities Program to promote the reduction of greenhouse gas emissions by improving energy efficiency at community level. In Tasmania the program has been delivered in conjunction with a non-government organization, the Tasmanian Environment Centre. The Student Housing Office of the Tasmanian University Union (TUU) successfully applied for a Cool Communities grant in February 2004 to investigate ways to encourage students to be more energy efficient, to encourage owners of the University's student housing stock to improve its thermal efficiency and to educate TUU staff on energy efficiency and greenhouse gas issues. Part of the grant allocation was used to establish a 'curtain library' from which students can hire heavy lined curtains for use in university housing for a bond of \$25 and, upon returning the curtains in good condition, have their bond returned (AGO 2004).

Students who wished to participate in the energy audit program were recruited through the Student Union website and through an information night at which information was handed out on ways to improve heater use and to do draught-proofing. As the TUU was aware of my field of research, I was offered employment conducting energy audits on the homes of volunteers recruited from the information night, at which I had been invited to deliver a talk on energy efficient behaviour in homes. In June 2004 I carried out the energy audits, and in the process was able to observe in detail the energy inefficiencies of 22 mostly older homes in the vicinity of the University. There was a follow-up meeting at which more detailed information sheets I had prepared on heater use and energy efficient home actions were distributed. To complete the audit program I prepared sheets for laminating to be

posted in each house summarizing the key steps necessary to run that specific house more energy efficiently.

There were some deficiencies common to many of the houses. If windows were timber-framed they were often sources of infiltration due to ill-fitting sash panes. When a student room was in a converted sleep-out, the timber sliding windows inevitably had gaps where the panes met. External doors often had a substantial gap beneath them (Figure 6.7). Chimneys had generally been sealed off but not always effectively. While student rooms were thermally zoned from the rest of the house for privacy reasons, heated living spaces were either unable to be thermally zoned or suffered from being treated as corridors, with one or more doors left open. Heaters were left on unattended in some living rooms, and a few students left heaters on in their rooms when they were not even in the building.



Figure 6.12: Large gaps under external doors

There were some shortcomings in appliance use, with many refrigerators and freezers having the thermostat set too low, and with most household and personal appliances being left on stand-by. These latter deficiencies are behavioural in nature, but one structural feature was remarkably common – the location of the hot water

system in an open space for 15 of the 22 houses, with 10 of those houses having the tank outside the building. Heat losses in such situations would be considerable, particularly for the two tanks which were exposed to rain (Figure 6.8). Hot water temperatures at delivery point were frequently excessively high, sometimes over 70°C, and thermostats were not readily adjustable.

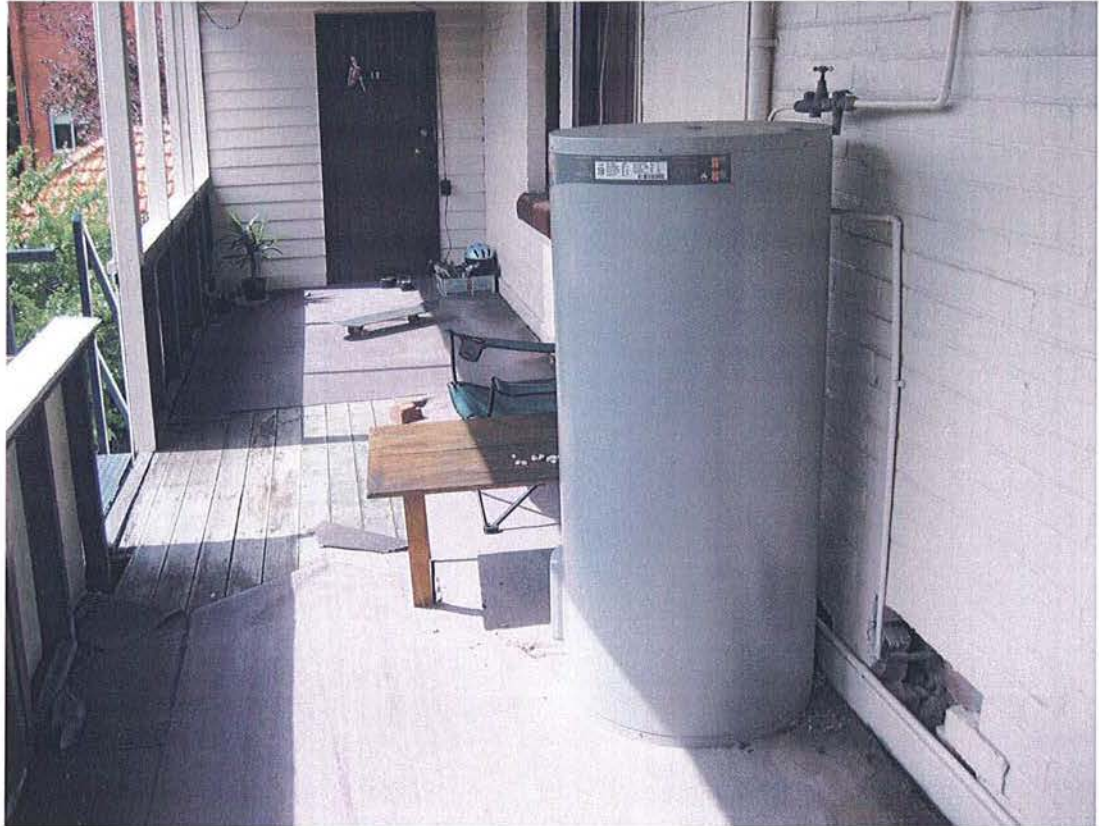


Figure 6.13: New hot water system exposed to rain (as is hole in wall)

The results of the audits on student housing indicate the frequency with which problems affecting the integrity of the building envelope occur in older housing in Hobart. Old timber window frames, especially sliding ones are often draughty, contributing to heat losses. External doors frequently have large gaps beneath them, adding to air infiltration. The audits also highlight the energy losses due to inefficient hot water system installation and operation which contribute significantly to home energy bills.

Through my association with Cool Communities in the student housing audit program, I was also invited to deliver a talk titled Retrofitting Case Study Preliminary Results at a Free Home Energy Saver Cool Communities workshop in

July 2004. I also gave a brief summary on the same topic to the SCRG Sustainable Housing Round Table Conference of representatives from housing industry, housing associations, building construction and association representatives in October 2004. As a result of that presentation I was invited to talk on simple practical measures to improve home energy efficiency at the Annual General Meeting of Shelter Tasmania, a housing advocacy association in November 2004. At the annual Tasmanian Sustainable Housing Expo in Hobart in November, I shared a stall with HCC at which I had information sheets on retrofitting techniques which I had prepared, and I delivered another talk on my preliminary results.

In each forum I have found considerable interest in the practical methods of conducting retrofits, as well as the best order to undertake actions. The questions people ask reflect their understanding of the deficiencies of their homes and their desire to rectify them. Working with Groups like Shelter Tasmania has the potential to yield information on the specific housing needs of the disadvantaged, and to supply them with information applicable to their situations.

A notable factor contributing to the opportunity to share in these different fora has been the community partnerships established between the Tasmanian Environment Centre, Cool Communities and the housing associations, and the personal energy invested by key actors in each group. Some members of one group are on the board of another and the networks established strengthen their ability to facilitate community change in the ways referred to in the Waterloo community study briefly discussed in section 2.4, which will be elaborated on in Chapter 7.

6.9 Summary

The retrofit of the Taroona House has yielded small reductions in overall energy consumption with attendant decrease in energy expenditure by the occupants. Due to the majority of reduction in energy consumption being in the amount of wood burnt, with a three per cent increase in electricity consumption there has been no decrease in greenhouse gas emissions, and if Tasmania had coal-fired electricity generation there would have been a slight increase in emissions. There have been significant gains in thermal comfort as a result of the retrofit, with average temperatures in the unheated bedrooms increasing by approximately 2.5°C in winter and the heated living space having increases of 4.5°C, both increases being relative to outside

temperatures. The residents have reported noticing the absence of draughts, the absence of vapour clouds when they talk, warmer bedrooms (this despite the numeric increase seeming small), linen drying more rapidly and no more mould growth on clothing in baskets. However, the most significant improvement they reported has been in the health of all members of the family, but most notably that of the children, who have experienced only brief minor colds since the retrofit in contrast to previous regular long colds and chest infections. The woman resident had suffered chilblains in winters prior to the retrofit, but they ceased within days of the retrofit, and the chest infection one child had at the time also cleared up within a week. The residents report a much-improved living experience in the house since the energy efficient improvements were made. The mould growth on the southern walls of the bedrooms in the winter of 2004 could have been prevented by installing insulation in the south wall of the house to keep the temperature higher on the inside surface of the wall.

The audits on student housing confirmed that some of the problems with the integrity of the building envelope in the Tarooma house are common to other older timber homes in the municipality, chiefly gaps around external doors and windows, but that there was a separate problem with poorly located hot water systems, often directly exposed to weather.

Interactions with individuals attending presentations on retrofitting techniques with reference to the Tarooma case study, made at a range of venues, have generated much interest and shown how keen people are to improve the thermal comfort of their homes.

Subsequently the charms of the East Coast, of Tasmania proved irresistible, and I built a post-and-beam recycled timber house on better-researched passive solar principles, and have lived in it since 1997. The house is warm as soon as the sun rises out of the ocean; guests arriving after sunset in winter marvel at its cosiness: 'But you haven't got a fire on?' Again there is a wind-generator, larger this time, for this coastal zone offers plentiful breezes. There are two photovoltaic panels, two flat-plate solar hot water collectors from the era of my first ones, and once more a slow combustion stove with hot water jacket, to supplement the hot water system (mostly in winter). A wood heater is used for just a few hours a night in the coldest three or four months, despite the clear skies and cold air drainage off adjacent hills causing more frosts than there were at the cabin in the North-West. (The fire-wood is grown on site.)

The windbreak trees are beginning to protect the house and garden from some of the prevailing winds – the garden is thriving and supplying food. Analysis of temperature monitoring in the living area and a bedroom confirms the pleasant living experience.



CHAPTER 7: REFLECTIONS

The impetus for this study came from many years of seeking low-cost practical solutions to improve the thermal comfort of houses I have lived in, or seeking to create economical, comfortable, autonomous living spaces where previously there had been degraded pasture. There were several questions that remained unanswered for me after these generally rewarding experiences: Why don't more people actively seek to improve their living conditions in this way – rather than just buying a bigger heater? Why is there no ongoing public campaign to encourage them to do so? Why is the only focus on energy efficient homes aimed at new constructions? These broad questions led to more specific research questions at the time of undertaking the study. How inexpensively could a retrofit be conducted? Would monitoring the house before and after the retrofit satisfactorily quantify the change in thermal comfort levels? How would the qualitative experience of the occupants compare with the numbers from the thermometers? Would the gains be worthwhile? These were the humble aims with which I embarked on the preparations for the retrofit case study. In the broader research I sought to ascertain why it is that energy inefficient housing is the norm, as well as the factors relating to lack of uptake of energy efficient upgrades of existing housing – both the top-down bureaucratic factors and bottom-up social factors. As a result of studies on Local Agenda 21 initiatives in the Coursework year I had completed before commencing this research, I felt that local government actions were possibly the best way to effect change in the community, but that I needed to investigate this further. My bias towards local government as an agent of change meant that my objectives included possible preparation of information brochures on energy efficiency improvements for people to make, brochures which could be disseminated by local government, and also the possible production of an incentive strategy for local government to encourage household uptake of these improvements, especially by landlords.

My initial research was into the scientific principles which inform the techniques of retrofitting – years of practice could have been based on misconceptions and incomplete information, and were reliant upon the now dusty old popular press publications! I commenced by looking into thermal comfort and was surprised to find that extensive controlled climate chamber studies like those of Fanger (1972) had resulted in a prescriptive optimal temperature for all people, and the setting of

inflexible national standards for building heating ventilation and air conditioning, based on findings that all people with the same activity and clothing like the same temperature in any season or climate. My experience of people is that they differ from each other in their choice of optimal temperature, and that individuals vary seasonally and put on more clothing when cooler, even inside. I was aware of cultural differences from my travels abroad – the city homes and commercial spaces in the USA always found me removing clothing. Fanger's 25.6°C optimal temperature was too much for me. Thus I identified with the thermal comfort studies of Olgyay (1963), Humphreys (1975, 1977, 1992), Rhee (1986), and Rohles (1981), all of whom conducted field studies of people in their usual work and living environments and found different comfort requirements for people according to culture, surroundings, attitudes and beliefs, season and climate, allowing for a wide range of acceptable thermal comfort conditions. They were also of the opinion that rather than air temperature and humidity determining thermal comfort, mean radiant temperature was most important (the large, cold, uncurtained window effect described in section 3.3). Their work was supported by Riordan's 1992 study of context relevance to thermal comfort, in which he found that international standards based on Fanger's work could lead to excessive heating in winter and excessive cooling in summer. Energy consumption would therefore be unnecessarily high. My research of heat transfer highlighted the importance of first sealing the building envelope to reduce infiltration of air and then selecting materials whose physical properties of thermal resistance, emissivity, colour and heat capacity need to be considered to minimise unwanted heat losses (and gains) and maximize heat storage. In Tasmania use of greater amounts of insulation than in the mainland states is warranted due to the higher number of degree heating days in the local climate zones, as mapped by Kalma and Auliciems (1980). Thus Tasmania's adoption of lower mandatory standards for new homes than Victoria as of 1 January 2003 will lead to unnecessary energy consumption to maintain thermal comfort in this state.

My next research was into the range of retrofit procedures available. I presented them in a sequence of increasing expense and complexity because of my interest in finding affordable solutions for inefficient homes. It also eventuates that there is little value in performing retrofits in a sequence different from this. The building envelope should first be sealed as much as possible to reduce entry of cold air and exit of warm air. Whilst this is not a complex operation, the materials being inexpensive and

easy to install, Pitts and Willoughby (1992, p.202) disabused me of any notion that it is therefore simple. The target is to reduce infiltration as much as possible – it cannot be prevented, especially in older homes. Insulation is the next most important operation, with ceiling insulation regarded as second to draught-proofing in cost effectiveness (Jensen 1988). The reflective foil laminate (RFL) used to reduce radiant heat losses, if taped at the joins would also be a useful frontline defence against infiltration. Builders almost never do this, in my observations of new constructions. Fibreglass batts are the most common bulk insulation material to reduce conduction losses but must be installed carefully to provide complete coverage of surfaces. Wall insulation is not easy to retrofit due to difficulties in accessing the wall space, but the retrofit case study I carried out has convinced me of its importance, as I will explain when I review that retrofit later in this discussion. Underfloor insulation is usually only considered worthwhile if the underfloor space is open to unrestricted air movement, as it was in my case study. In all homes in cool climates windows should be insulated against radiant heat losses at night by the use of heavy lined curtains. Pelmetts above the curtains are vital to prevent convective heat loss, although there may be some who find them unfashionable. Unfortunately, insulating with commercial products is relatively expensive and beyond the means of many disadvantaged people. While the use of less expensive materials would be advantageous to them, availability is restricted and slow to change due to the glacial pace of legislative action to amend building codes (McDonald 2004, p.3). This situation is difficult to circumvent due to insurance being connected to adherence to the code. The last target for insulation is the hot water system, a source of heat loss which was to recur several times in the research. As the greatest contributor to greenhouse gases in a house (ABS 2002, p.3), it often lurks neglected in an obscure place, or worse still in Tasmania, outside, quietly shedding heat into the air. It should be regarded as the greatest contributor to stand-by energy losses in a house, and needs to be heavily insulated and have its hot water pipe lagged where exposed, and its cold pipe lagged for the first metre, an inexpensive exercise and simple enough for most residents to do.

The third category of retrofit aims to improve solar gain into the house. While some of these techniques are less expensive than insulating, there is no point increasing the solar energy entering a house if the building is not insulated to prevent loss of the extra heat. There are three ways to improve solar gain, the simplest of which is the

direct gain system, relying upon substantial glazing in the north wall of the house, and its principles should be employed to heat any rooms of a house with extant north-facing glazing. Curtains need to be open during the day and closed after sunset to maximise heat gains and minimise losses. Perhaps the most effective solar gain system is a sunspace as the created space can be used to extend the growing season of plants (Clarke 1979) or as an additional living space (Vale & Vale 2000), while simultaneously feeding warm air into the house. It suffers from the fact that in addition to the expense of construction, there are council planning fees and subsequent rate increases due to the increased value of the house. Rather than these disincentives, councils could promote purpose-built energy efficient sunspaces by offering rate reductions for people who add them to their house as well as planning fee rebates.

The final retrofitting technique is adding thermal mass, the most difficult and expensive if the house has no substantial thermal mass to begin with. However, if a house has a concrete slab, effective thermal mass is readily increased by removal of any floor covering or furniture which shades it from solar gain and prevents the slab from coupling with the room air. There are aesthetic considerations, as concrete is unattractive, as well as being a poor surface for the elderly if they fall. In Table 3.1 (section 3.3.2) it can be seen that linoleum and vinyl tiles both have considerably lower R-values than carpet and would thus be less of a hindrance than carpet is to the slab coupling with the air. Thermal mass acts to slow temperature increase during the day and the re-radiated stored solar gain at night decreases temperature drop. Thus, overall diurnal temperature range in a space is reduced. A timber-framed, timber-floored house is at a major disadvantage in energy efficiency through its lack of thermal mass, so much Tasmanian housing, with the highest proportion of timber dwellings in Australia (ABS 2003) is poorly suited to heat storage in a cool climate.

After investigating the retrofitting techniques and carrying out the retrofit, I had my first inkling that the research may be about to change direction. When the female tenant at Hobart City Council's Taroona house first spoke of the effects of the retrofit on the health of the family (section 6.6), it was a surprise to have such immediate feedback. At that stage my research focus had been on the historical path which had led to widespread inefficient housing – a line of investigation which led from transplanted nineteenth century European housing to 1960s tract housing, with house

design in the hands of builders interested in simple rapid construction. Initially I did not swerve from my path, continuing to research advantages of energy efficient housing and the extensive literature on reduction of energy consumption and the financial gains possible. However, my aim to research equity issues revealed two different paths taken in the northern hemisphere. The first was the extensive range of Weatherization Assistance Programs that had been conducted in the USA from the time of the first oil crisis in 1973-4 aimed at disadvantaged groups: low income households, the elderly and the disabled. A survey of 132 programs found the most common goal was to make energy services more affordable to low-income families (Pye 1996, p.2). The programs were federally mandated and funded, but largely delivered by the private energy suppliers. Funding has been progressively withdrawn from these programs through the 1990s. In the UK the Home Energy Assistance Scheme did not commence until 1991 and was also directed at improving draught-proofing and insulation in the homes of people receiving income support, aged over 60 or disabled, providing grants to carry out works (Ekins, Russell & Hearngraves 2002, p.43). The principal purpose of the scheme was the reduction of fuel poverty, although evaluations showed that there was takeback of between 12 and 82 per cent of fuel savings in the form of increased thermal comfort, with an average of about 50 per cent (Milne & Boardman 1997, p.20). The scheme has been extended since 2000 and is now part of the UK Government Climate Change Strategy, offering larger grants for insulation and improving heating targeted at households on income support with children, the disabled and elderly. A growing body of research in Europe has been establishing the links between poor energy efficiency in housing, damp houses, fuel poverty, respiratory and cardiac disease and excess winter mortality (Sommerville *et al.* 2000, Healy & Clinch 2002, Zureik *et al.* 2002, Gunnbjornsdottir *et al.* 2003, Wilkinson *et al.* 2004).

The Australian approach to improving residential energy efficiency has been minimalist compared with those in the USA and UK, which accounts for the lack of energy efficient upgrades of housing in this country. Largely shielded from the energy crises by low-levels of dependence on oil for home energy, the few federal housing initiatives in the early 1980s were soon abandoned (Parnell & Cole 1983). The Victorian Government ran the Home Energy Advisory Service and the Community Home Energy Improvement Scheme in the 1980s as a result of having strong university research programs in the field and a government keen to use

demand side management strategies to reduce state energy consumption (Harries 1996, p.306), but the programs were limited to the term of that government. The strong vested interests of governments and bureaucracies in Tasmanian hydro-industrialization meant that the State Government has had no energy efficiency programs. The federally funded Cities for Climate Protection and Greenhouse Challenge programs may be no more effective than the implementation of Local Agenda 21 action plans has been, as they rely on under-resourced local government delivery, and are currently marketed as greenhouse gas reduction programs. Burningham and Thrush (2003, p.534) found that the very disadvantaged, who most need to make energy efficiency improvements do not relate to appeals to act on global environmental grounds. They also lack the capital to invest in even the most minor improvements (Katz & Morgan 1983, p.223, Shipworth 2000, p.15). Australia, with no fuel poverty strategy and no low-income assistance schemes for retrofitting is failing its disadvantaged. No state in the nation has as many disadvantaged as Tasmania, with 40 per cent of the population on income assistance (ABS 2001). It is generally accepted that electricity disconnection rates are indicators of consumer hardship. The State's domestic energy provider, Aurora Energy, has had a disconnection rate five times that in Victoria (Tasmanian Electricity Ombudsman 2003, p.4). Disconnection rates were reported to have declined in 2002, but this may be due in part to the marketing of pre-payment meters to the disadvantaged as a way (supposedly) to have no more energy bills, creating a situation where they pay a higher tariff for their energy and levels of disconnection are hidden (the act of disconnection having been effectively privatised) (Sharam 2003, p.12). The situation of the disadvantaged in Tasmania is exacerbated by living in the oldest, poorest housing in the coldest climate in the nation. A new approach to their plight is urgently required.

The country with energy efficiency program delivery nearest to the Australian model, although more pro-active, is Canada. A small-scale delivery of a national program which was most successful in Waterloo Region, Ontario (discussed briefly in section 2.4) could inform a local strategy in Australia. In the first 12 months of the Canadian Government running the EnerGuide for Houses (EGH) home energy audit program, several broad national and provincial marketing strategies managed to attract three households to participate in Waterloo Region. In the same period the Residential Energy Efficiency Project (REEP), used social and community-based

social marketing tools to recruit 891 households to participate (Kennedy *et al.* 2000, p.57). EGH is one of the programs administered by the Office of Energy Efficiency in the federal department of Natural Resources Canada (NRCan), the program being delivered by different agents around the country, including not-for-profit environmental organizations, private for-profit organizations, building associations and provincial agencies. NRCan provides support for delivery agents including assistance developing marketing strategies, and the Canadian Government subsidizes the cost of the audit by buying the EGH audit file. The REEP model was a unique delivery agent of EGH involving a partnership between the Faculty of Environmental Studies at the University of Waterloo and the Elora Centre for Environmental Excellence, a member of the Green Communities Association (GCA). GCA was the delivery agent for almost all of Ontario (p.59).

The REEP marketing strategy was designed to encourage homeowners to take the first step – to telephone or e-mail to make a booking for an energy audit. Other social marketing techniques were used to facilitate behavioural change, but as they work best in face-to-face situations, the booking was needed first. ‘Social marketing aims to change and mitigate those barriers that limit the broad adoption of a belief or behaviour’ (Kennedy *et al.* 2000, p.60), and differs from traditional marketing in that its ultimate goal is not to benefit the sponsoring body but the target audience (and broader society). REEP decided to adopt a diverse yet integrated marketing approach to encourage people to make an audit booking, employing some traditional marketing materials (posters and flyers) and some community-based social marketing (CBSM), focused on the need to have personal contact with the community to effect change. CBSM recognizes the ideas I encountered in undertaking research for section 2.4: the range of barriers to the uptake of energy efficient actions identified by Crossley (1981); the need to consider the variations in the target audience - the market segmentation of Hutton and McNeill (1983); the importance of encouraging attitudinal and behavioural change (Knutson (1983); and the value of social diffusion techniques (Aronson and Yates 1983) where members of a community are more influenced by a peer who has tried energy efficiency than they are by an advertising campaign.

Firstly REEP personnel conducted a literature review to identify the barriers to booking an audit, which suggested cost, time taken for the audit, uncertainty of the

usefulness of an audit and credibility of the delivery agent. Through diverse partnerships and funding arrangements they kept the cost to CAN\$25 (in comparison with up to CAN\$200 elsewhere in Canada), university students were employed to assist with audits, reducing audit time from four and a half hours to two hours, EGH was a familiar government 'name-brand' on energy efficient appliances, and the delivery agents were seen as independent, non-profit-making organizations. When households booked an audit they were asked how they had heard about the program, revealing that in the first 12 months from May 1999 to April 2000 most were referrals from friends and relatives (36%), followed by local media stories (28%), community-based events – school visits, workshops, talks to neighbourhood, industry and housing associations (18%) and direct marketing (16%) (Kennedy 2000, p. 63). The marketing was directed according to evaluation of an earlier Green Home Visit program in Ontario which informed an hypothesis that program participation was influenced by income, education level, recency of house purchase, house age, home ownership and house condition. Use of 1996 census data enabled the targeting of neighbourhoods with chosen values for each of the criteria. Experiments were conducted to evaluate response rates to the use of local and national promotional material, showing the former to be much more effective, especially when the information pamphlet was combined with a REEP newsletter including stories about the goals of REEP, research findings of the first 400 homes audited and REEP's work with local community groups. Simultaneously REEP used television to run local news items. No media advertising was used in the entire program, and evaluations of the concurrent national advertising campaign revealed the latter to have generated very few bookings (p.69). I consider the methods used in the REEP initiative to be most instructive about the need to emphasise local partnerships, build social capacity, use personal contact and have a directed marketing strategy with highly specific aims. In this way different market segments can be aided to improve their housing, local employment is boosted and expenditure is optimised. Confirmation of the importance of partnerships in delivery of energy efficiency programs is to be found in Pye's 1996 review of such programs to low-income households in the USA, with much higher uptake rates where the delivering utility did not act alone. In Tasmania partnerships could involve organizations such as Housing Tasmania, Shelter Tasmania or Anglicare combining with local government.

My research into the background and local context for retrofitting housing indicates that internationally agreed strategies for empowering local communities to implement sustainable practices and contribute to improved chances of global sustainability have been limited by the emphasis placed on them by national governments (Desai 2001). In Australia that emphasis has not been great, and local government involvement has been slow with only 34 per cent of Australians living under Local Agenda 21 action plans in 2004, eight years after the whole nation should have been covered. Councils are under-resourced to carry out the work, but there have been some highly effective projects in the Cities for Climate Protection Program established in 1998. The City of Newcastle through its service unit Australian Municipal Energy Improvement Facility (AMEIF) co-ordinated a Greenhouse Action Showcase which I examined in section 5.5. Perhaps the great strength of the project came from a University partnership (as did Waterloo's REEP), this one with the National Solar Architecture Research Unit (SOLARCH), now the Centre for the Sustainable Built Environment, at the University of New South Wales. Although the other partner was a utility EnergyAustralia, which could have led to some community skepticism as reported in the USA with energy efficiency programs delivered by energy supply companies (Katz & Morgan 1983, p.224, Hutton & McNeill 1983, p.286), SOLARCH was independent and well-established in passive solar research and design. The three programs delivered resulted in substantial reductions of greenhouse gas emissions and also found poorly located water system tanks and exposed pipes to be contributing significantly to energy losses. They installed a thermal blanket around a hot water tank, a retrofit regularly performed in the USA in low-income weatherization programs and known as a 'water-heater tank wrap' (Pye 1996, p.2).

In Taroona, my case study retrofit of draught-proofing measures, floor and ceiling insulation and heavy curtains with pelmets resulted in increases in average temperatures of approximately 2.5°C relative to average external temperatures in the unheated bedrooms on the south side of the house, with increases of 4.5°C in the heated living spaces on the north side. These temperature increases were sufficient to eliminate clouds of vapour from appearing when members of the family spoke and to make the linen dry more quickly and not be prone to mould growth, but most notably to contribute to the improved health of the family, particularly the children. Lingering winter ills disappeared and it was noticeably easier to heat rooms and they

remained warm longer. This family is not attempting to heat their whole house to 18°C and the living areas to 21°C as recommended in the UK Fuel Poverty Strategy (Scottish Executive 2002), nor to maintain each room above a minimum of 16°C (WHO 1989), with bedroom temperatures averaging 11-12°C in winter. Neither do they have high takeback levels, with electricity consumption increasing 3 per cent and wood consumption ceasing, yet they report minimal ill-health after the retrofit and quicker recovery. These observations lend strength to the arguments of the field study branch of thermal comfort scientists that there is no single temperature which defines thermal comfort for all, and to the argument of Riordan (1992) that heating to climate-chamber-determined international standards could result in excessive energy consumption. The health improvements in the household temperatures prevailing in Taroona suggest that some of the nominated minimum temperatures for good health which I found in my research may be warmer than necessary. Despite the major shading problem for the Taroona house, the thermal comfort gains from this retrofit were sufficient to improve the health and (chilblain-free) comfort of the occupants. The appearance of mould on the southern walls of the bedrooms in the second winter after the retrofit indicates that these walls would have benefited from insulation, which would have kept their inner surfaces sufficiently warm that the relative humidity of the air layer next to them did not get high enough to support conditions for mould growth. As a result of this mould occurrence I would recommend that wall insulation be installed at least in the southern walls when retrofitting old timber houses which have unheated rooms on their southern side.

I consider that the case study has shown the potential for energy efficient retrofits to be beneficial for the occupants, particularly those in the older and less efficient timber housing of which the proportion in Tasmania is higher than in the rest of the nation, in terms of reduced energy consumption (and therefore reduced greenhouse gas emissions), improved thermal comfort, *but most importantly for the health benefits*. The relationship between health, quality of life and equity as foundational principles of sustainability requires that significant weight be apportioned to the improvements in these aspects of the lives of the tenants in the Taroona house. The number of households that could afford the retrofit conducted at Taroona is limited by household income, although if the elements of the retrofit were carried out incrementally the measures become more affordable. A report prepared for the Australian Greenhouse Office concludes that :

There will be a significant number of households who can not afford energy efficiency no matter how favourably it is financed. For these households, direct grants or subsidies (or direct provision of energy efficiency services) will be the only feasible way to promote energy efficiency investment. Retrofitting programs by public housing authorities are examples, and although rents could be raised to ensure user pays, it is understood that this is not undertaken as a result of such programs (Key Economics 1998, p.60).

Finally I would like to consider some design issues which may seem, at first glance, beyond the scope of this study. In a study titled 'Thermal performance and life-time costs of public housing units in Victoria and Tasmania', (Coldicutt *et al.* 1978, p.6) highlighted the importance of orientation of new buildings to within 15° of north, which must start with the design of subdivisions. Their suggestions are supported by Pitts and Willoughby (1992, p.195) who stress the need for correct orientation in the cool temperate UK conditions, and, like Coldicutt *et al.*, add the need to establish windbreak protection. Coldicutt *et al.* further advised that those who design future public housing should aim to have living spaces on the north side of the house, extensive north wall glazing and minimal windows on south, east and west walls. Whilst my work has been directed at inexpensive retrofits for moderate to low income households, it is easily overlooked that, despite living in housing which is generally more energy efficient, the wealthy consume considerably more energy per household than do the poor (Shipworth 2000, p.15), having more fittings and appliances, and resources to pay the bills. In the annual Tasmanian Housing Industry Association awards for 2004, 'House of the Year' was awarded to a renovation of an 1890s brick home (*The Mercury* – Special Supplement 19 November, 2004, pp.3-4). The two page article mentioned the three heat pumps and three hot water systems which had been installed, but not the full-width sunspace across the north-west wall of the house, feeding solar energy and light into the living area. (This sunspace would improve daytime energy efficiency but would be an enormous source of excessive heat gain on summer afternoons and of heat losses at night, as there is no way to isolate it from the room.) The bathroom has 10 inefficient low-voltage downlights. *This household could consume as much energy as an entire street of disadvantaged people in public housing doing without adequate heat to save money, but is given the accolades of the industry, and largely, one suspects, for reasons closely aligned to cosmetics and the market.* Greenhouse gas emission reduction programs also need to target the consumption patterns of those who may stand to gain nothing personally

important from improving energy efficiency. Late in the *Mercury* supplement is the 'Greensmart Building of the Year: Energy-Efficient Housing Award', a modest-sized structure with photovoltaic and solar hot water panels attached all over its roof, in a design described as a 'spectacular futuristic home' (p.14). As long as energy efficiency is marginalized as a separate genre, as long as it is treated as a curio, and is not mentioned in mainstream or prestigious awards, it will not be seen as an integrated part of sound practice design in housing.

During the period between 2003 and 2004 Tasmania experienced a 'building boom' that offered the opportunity to establish a new era of energy efficient suburban design. The Tasmanian Government's announcement in November 2004 of a plan to construct public housing in a partnership between Housing Tasmania and Macquarie Bank represents a chance to construct well-oriented, appropriately glazed, properly landscaped housing of the type Coldicutt *et al.* recommended in a section titled 'Recommendations for immediate change' (1978, pp.3-6) in their report which assessed the early public housing estate at Bridgewater, Tasmania. The authors modelled improvements which would result in savings in initial capital costs for construction as well as reduced space heating costs (p.8). The need for well-planned energy efficient design in new housing is no less pressing a quarter of a century after their report. I have raised these new home design issues here because today's new housing is tomorrow's existing housing, and retrofitting is inherently less efficient than building correctly initially.

Increasingly I have cast a critical eye over houses I visit, or see under construction as I drive past – so many wasted opportunities to create a comfortable sustainably heated living space. Above all, however, I feel for the occupants of existing, older, timber-framed houses. Theirs is an experience I could not identify with until I was renting such a building near the University of Tasmania when commencing my Masters. It huddled in the shade behind a two-storey house to the north, its two northern windows admitting steeply angled sun for only about four months in summer. It was gloomy and frigid for eight months of the year, and unreasonably hot when the sun finally found it. No heater could warm a room, as all the heat gathered near the four-metre ceilings and snuck away into the night. It was a dispiriting existence. Despite running just one 2000 watt heater frugally, as I would, and one compact fluorescent light in one room with the doors shut, the power bill still seemed exorbitant. I began to feel for people raising families in similar modern caves.

I thought back on my experience of homes, and remembered some of the simple arrangements I had made to gather and retain heat, and of my friend in Minnesota with his home-made solution to heat loss. Surely it must be possible to show that substantial improvements to the living experience of a large number of people could be made by retrofitting their homes, often doing the work themselves, and at low cost . . . but how to reach them, and perhaps hardest of all, how to reach the most disadvantaged of them?

CHAPTER 8: CONCLUSIONS AND FURTHER RESEARCH

Australian housing, and that in Tasmania in particular, has historically been poorly designed for local climatic conditions and for energy efficiency. Apart from a brief period in the 1980s, there has been little action taken to improve the energy efficiency of the existing building stock in Australia, in contrast to some programs conducted in the USA and the UK. At the Rio Earth Summit in 1992 global agreement to embark on a path towards ecologically sustainable development and the implementation of Local Agenda 21 action plans for sustainable practices at community level has resulted in differing degrees of national implementation. The Australian Government has not prioritised LA21 planning, and has not ratified the Kyoto Protocol which was designed to strengthen the commitment made by the industrialized nations to the United Nations Framework Convention on Climate Change, also at the Earth Summit. In 1998 the Australian Greenhouse Office was established to promote the reduction of greenhouse gas emissions and, in partnership with ICLEI, established the Cities for Climate ProtectionTM Program to deliver funding to local governments for emissions reduction projects. Improving residential energy efficiency was a listed government priority in 1992 and again in 1997, but under CCPTM councils choose their own strategies for emissions reduction.

The Sustainable Communities Research Group at the University of Tasmania formed a partnership with Hobart City Council, a member of the CCPTM Program, which funded the retrofit of one of council's houses at Taroona, Hobart. As part of a study on inexpensive energy efficiency retrofits, the project showed small reductions in overall energy consumption (including wood), modest improvement in thermal comfort conditions in the house and significant improvement in the health of the residents, especially the children. Associated research indicated that health and housing issues are closely linked. The importance of energy efficient housing for the health of the population across the temperate and cool temperate regions of Australia, in particular the disadvantaged groups, makes it imperative that retrofit programs be instituted to target assistance to the most needy. Energy efficiency programs need to be delivered by partnerships involving respected independent organizations like universities, local housing bodies and non-government organizations. Programs need to be carefully researched, targeted and delivered with personal contact and locally prepared materials. One of my objectives at the beginning of this study had been to

investigate the production of information brochures for Hobart City Council to distribute, but my research suggests that little value is to be gained from such distribution if it is not in the context of a well-directed social marketing program.

In the final analysis, the significance of this research is that in its attempt to show that inexpensive retrofitting could improve energy efficiency, reduce energy bills and improve thermal comfort levels, the study found evidence that the most significant gains for the residents were in their state of health. These findings support a growing international body of evidence linking serious detrimental health conditions with cold, damp, inefficient draughty housing – conditions which have their greatest toll on the young, the elderly and low-income people in poor health. Many of the most disadvantaged are tenants, and thus unable to invest in their housing, so to ease their situation local government has the important role of providing substantial incentives to landlords to invest in retrofits. Councils, state and territory and federal governments need also to consider strategies to encourage residents to undertake retrofits and energy efficient extensions to their homes such as sunspaces.

There has been very little research into energy conservation in Australia. Almost none of this research has been undertaken by social scientists and published in academic journals (Shipworth 2000, p.11).

In my research I found several areas of burgeoning studies overseas that are seriously under-represented in Australia, and in Tasmania in particular. The following areas of research could yield information which would clarify housing conditions and the relation of housing to occupants' health:

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- Retrofit studies on larger numbers of houses correlating house condition, thermal comfort conditions and health of occupants pre-and post-retrofit;
- The institution of regular House Condition Surveys for Tasmania/Australia;
- Research into the house improvement needs of disadvantaged groups;
- Fuel poverty studies for Tasmania/Australia;
- Excess winter mortality surveys for Tasmania/Australia;
- Research on temperature and humidity in mouldy, damp housing pre- and post-retrofit – in association with the state of health of the occupants; and
- Post-retrofit thermal comfort studies.

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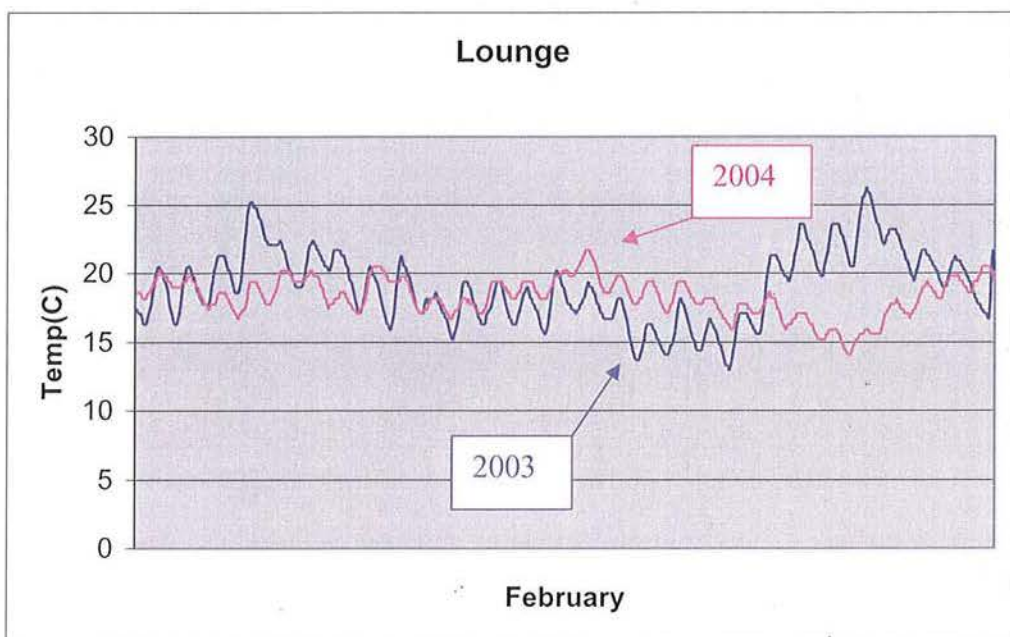
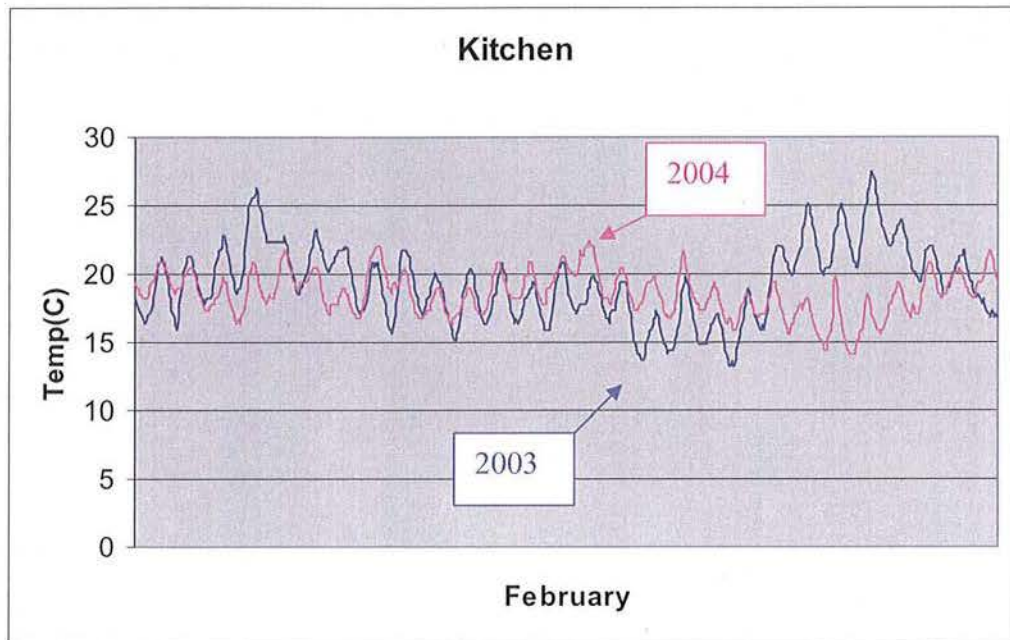
APPENDIX 1

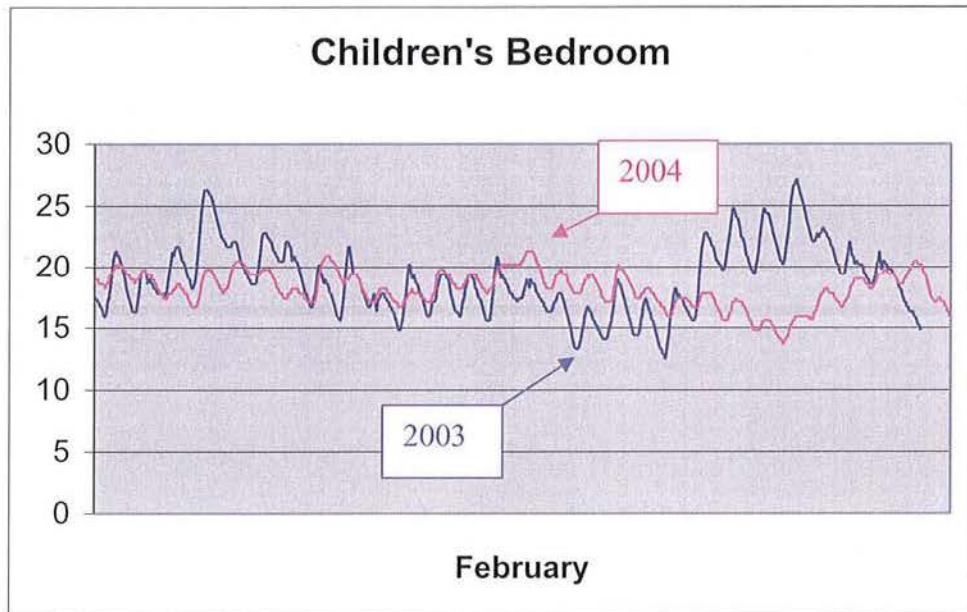
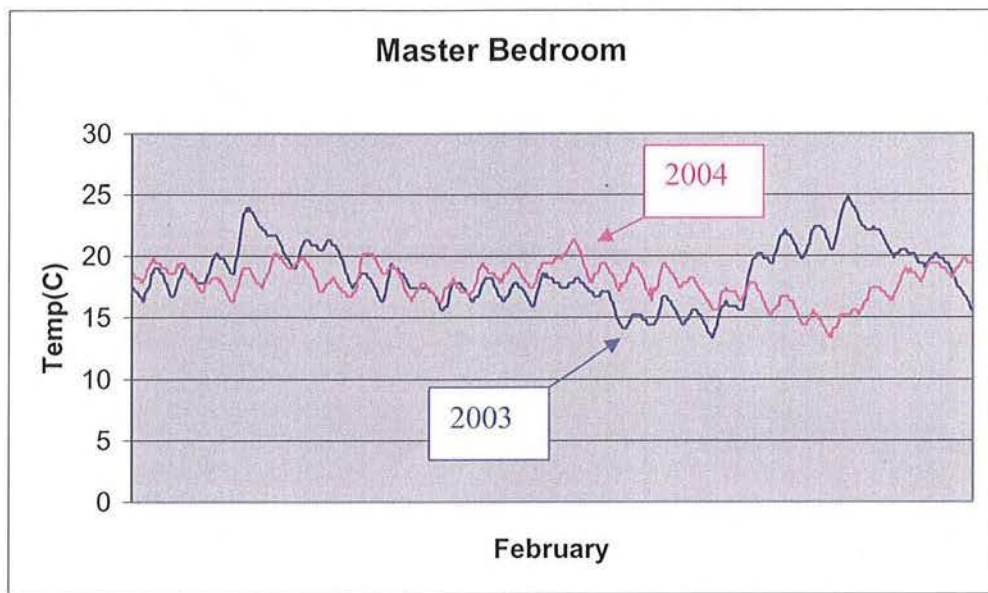
AVERAGE EXTERNAL TEMPERATURES

MONTH	On-site External Average Temp. (C)	Bureau of Meteorology Av. Temp. (Battery Point) (C)
Jun 02		10.4
Jul 02		9.7
Sep 02		11.2
Oct 02		12.3
Nov 02		15.1
Dec 02	15.7	16.6
Jan 03	18.0	19.3
Feb 03	16.7	17.5
Mar 03	14.5	15.2
May 03	11.3	12.0
Jun 03	9.2	10.0
Jul 03	8.0	9.1
Sep 03	8.3	9.7
Oct 03	-	11.1
Nov 03	12.4	14.8
Dec 03	16.6	16.2
Jan 04	15.9	16.4
Feb 04	15.3	16.7
Mar 04	15.9	15.4
May 04	8.4	12.7
Jun 04	7.1	9.0

APPENDIX 2

MONTHLY COMPARISON GRAPHS IN A SUMMER MONTH





APPENDIX 3

SITE PLAN AND HOUSE PLAN



'TAROONA HOUSE' Plan View

